Effectiveness of Street Sweeping in Incline Village, NV

Final

December 2011

In collaboration with

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Funders:
USDA Forest Service, Erosion Control Grant
NDSL, Lake Tahoe License Plate Grant
Washoe County, in-kind labor and equipment

EXECUTIVE SUMMARY

A 752 m length of Village Blvd. in Incline Village, NV was divided into two “study areas” and monitored for two years to characterize the benefit of frequent street sweeping using a high efficiency dustless, waterless street sweeper. Although many studies of street sweepers have been generated, this study is different because it specifically investigated the effectiveness of a dustless sweeper to remove sub-16 micro-meter (µm) sediment during winter conditions on an active road where traction control material was frequently applied. To understand the mass balance of sediment in the study areas, samples were collected from the road using a vacuum cleaner, from the material collected by the street sweeper, from material accumulated in drop inlets, and from stormwater discharging from the study areas.

This report contributes to understanding the characteristics of sediment on Village Blvd. in Incline Village, NV and the capabilities and limitations of street sweeping. This report also has implications for the rest of the Tahoe Basin because the basic behavior of road sediment and street sweepers are believed to be similar. However, results could vary because the use of different traction control material, different technology street sweepers, and different operational procedures may not produce the same results. The operational profile guiding this study was to have the road maintenance crew of Washoe County follow existing operational procedures as much as possible which conveniently coincided with the study objective to sweep as frequently as possible.

The Washoe County street sweeper collected an average of 123 g/m^2 where as the vacuum indicated the sweeper had collected 61 g/m^2 of total sediment each time the street was swept, 5.1% of which was fine sediment (less than 16 µm). The street sweeper removed an average of 74% of total sediment and 43% of fine sediment (i.e., less than 16 µm) on Village Blvd. By conducting two controlled “washoff” experiments, street sweeping was shown to reduce fine sediment in stormwater by 50%.

The minimum practical fine sediment mass per unit area that the street sweeper could achieve was 3.3 g/m^2. Equating 3.3 g/m^2 with road condition may help maintenance crews decide when sweeping a street may be impractical.

Drop inlets that drain the study areas collected a significant mass of sediment, perhaps as much sediment as found in stormwater. However, only 7.4% of the sediment mass in the drop inlets was fines, whereas fine sediment was 62% of stormwater sediment mass. As a minimum, the drop inlets appear to play a significant role in decreasing maintenance requirements for downstream assets, and the drop inlets may have a role in decreasing fine sediment mass discharged from paved roads.

One mystery this study was unable to answer involved the mass balance of road sediment. The mass of traction control abrasives applied to the road represented only 4.6% of the sediment collected by the sweeper. The remaining 95.4% of material collected by the sweeper had a different source. Several possible sources are suggested, but road wear is the most likely candidate.

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INTRODUCTION

Lake Tahoe's clarity has decreased approximately 30 feet over the past 40 years (LRWQCB and NDEP 2010) and, as a result, the lake has been listed as an impaired waterbody for clarity in California and Nevada. As required by EPA guidance, a total maximum daily load (TMDL) was developed after a five year study and found that bio-available nutrients (ortho-phosphate, ammonium, nitrite, and nitrate) and fine sediment particles of less than 16 μm in diameter were the primary causes of clarity loss (LRWQCB and NDEP 2009). Of those pollutants, 66% of the clarity reduction was attributed to fine sediment, and urban stormwater was found to be the largest source of fine sediment (72%) (LRWQCB and NDEP 2009). These two fractions indicate approximately half the reduction in lake clarity is fine sediment originating from the urban upland.

Lake Tahoe receives 30 to 60 inches of precipitation annually primarily in the form of snow. To improve traction and traffic safety, deicing salt and sand (i.e., traction control material) are applied to the roads throughout the winter and there is concern this material becomes a pollutant in stormwater runoff. The USEPA (2007) found that traction control material was ground into finer particles by vehicular traffic, and studies in the Tahoe basin have identified the use of traction control material as the cause of increased emissions of dust from roadways in the winter (Kuhns et al. 2007, Gertler et al. 2006). But there are many other potential sources of roadway sediment include atmospheric deposition, track-in, sloughing and/or runoff from adjacent land uses, and the breakdown of the road surface. The sinks for fine roadway sediment are stormwater washoff, atmospheric entrainment, and cast-off by snowplows.

To help document the reduction of fine sediment throughout the Tahoe Basin, the Lake Tahoe TMDL program has created an elaborate system to inventory, evaluate, and assess effectiveness of treatment systems; source control measures in the form of ground cover and street sweeping are also included in the tracking and assessment system (PLRM Development Team 2009, Lahontan and NDEP 2008 and 2009).

The Lake Tahoe TMDL has motivated the search for systems and practices to most effectively reduce the mass of fine sediment in stormwater under the conditions found in Lake Tahoe. Because it is difficult to remove fine sediment already suspended in stormwater, there is a renewed focus on preventing the creation of fine sediment or removing the fine sediment at the source. One of the least understood aspects of fine sediment source control is the efficacy of street sweeping. The Pollutant Load Reduction Model (PLRM) incorporates sweeping practices into the model, although the technical documentation acknowledges the lack of Tahoe-specific data limits the accuracy of model (PLRM Development Team 2009). Nevertheless, it is widely assumed by federal, state, and local Lake Tahoe agencies that frequent street sweeping improves air and water quality. For example, to help promote the use of street sweepers in the Lake Tahoe basin, TRPA has permitted the use of water quality mitigation funds for the purchase of "high efficiency" street sweepers (TRPA memo, Oct 2008 A/Q 2008-06). Other funding agencies also allow jurisdictions to purchase street sweepers with grant funds.

This study seeks to understand the sediment mass and size distribution typically found on a primary county road, the effectiveness of an advanced technology street sweeper, the ability of street sweeping to improve stormwater quality, and other data regarding strategies for reducing fine sediment to Lake Tahoe.

Past Research

The build up of roadway sediment is dependent on many factors including street conditions, adjacent land use, traffic volume, traction control practices, and other factors such as wind (Pitt et al. 2004 and Center for Watershed Protection 2006). The efficiency of sediment removal by street sweepers depends on the type of sweeper, frequency of sweeping, how the sweeper is operated, antecedent sediment moisture, and particle size distribution (Pitt et al. 2004 and Center for Watershed Protection 2006). For example, a brush type sweeper will remove less material, and in particular, less fine sediment than a vacuum sweeper (Selbig and Bannerman 2007). In addition, the more sediment on the road, the greater the percentage removed; however, there is a minimum mass per unit area below which a street sweeper is ineffective (Pitt 1979). The vast majority of sediment mass is typically found near the curb, and curb-side sediment is comprised of the greatest percentage of large particle sizes (Waschbusch 2003, Gottker 1987, Deletic and Orr 2005, USGS 2003, and Sartor and Boyd 1972).

Removal of the coarse fraction of road sediment is important primarily for aesthetic and safety reasons, whereas removal of the fine fraction is important for air and water quality. Studies have shown that street sweepers are more effective at removing coarser (>63 μm) sized particles, whereas rain events, even low energy rain events are effective at removing the fine sediment fraction (Pitt et al. 2004, USEPA 1983). Street sweeping studies using mechanical broom sweepers found that the pickup efficiency of particles <100 μm was 20% (Sartor and Boyd 1972). Over time however, innovations in street sweeper technology have improved the ability of sweepers to pick up finer sized particles. Sutherland and Jelen (1997) found that 70% of <63 μm sediment could be removed utilizing small-micron surface cleaning sweepers.

Despite the fact that street sweepers can collect a large portion of fine sediment, documenting a corresponding improvement in water quality has been elusive. Numerous studies have examined the efficacy of street sweeping at reducing stormwater pollutants resulting in an inconclusive body of scientific work. Some studies show inconsistent improvement in runoff pollutants (Zarriello et al. 2002, Pitt 1979) while others show no improvement or degradation in water quality (Schilling 2005, NURP 1983, Selbig and Bannerman 2007, Waschbusch 2003, Grottker 1987, and USGS 2003). One consistent conclusion is that not all sediment present on the roadway is available to be mobilized by water (Pitt et al. 2004), but the fraction that *is* mobilized is the finer fraction often at high concentrations (Kang et al. 2009, Selbig and Bannerman 2007, and Irish et al. 1995).

Authors of sweeper papers often hypothesize why water quality did not show improvement when logic strongly suggests it should. One common hypothesis is that sweeping benefits are very dependent on numerous site-specific parameters such as road condition, sediment composition and particle size distribution, sweeper type, and sweeper operations. To control the number of variables, some studies artificially manipulated aspects of the system such as using synthetic sediment to establish removal efficiency for a known particle size (ETV 2006, AQMD 1999, and other studies summarized by USGS 2007). Some studies simulated rain events on closed roads to control the intensity and rate of precipitation and to efficiently collect runoff (ETV 2006, Deletic and Orr 2005). However, simulating a typical scenario experienced in the Tahoe Basin require melting snow, application of road abrasives, frequent use of snowplows (removing snow and road sediment), and the dynamics between vehicle tires, road abrasives, and the road surface. This scenario would not be easily simulated in a completely controlled experiment.

For additional background, the following studies and reports conducted extensive literature searches on other sweeper studies and have comprehensive summaries: Rochfort et al. (2007), Deletic and Orr (2005), Kang et al. (2009), Zarriello et al. (2002), and the Center for Watershed Protection (2006).

Goal and Objectives

The goal was to establish methods and procedures necessary to quantify the sediment mass on a road and in stormwater runoff.

The objectives of this study three fold:

1. Characterize the efficiency and effectiveness of a high-efficiency street sweeper at removing sediment from an active road.
2. Determine if street sweeping reduces the mass of fine sediment particles in stormwater.
3. Understand the mass balance of sediment on a roadway in the winter.

Site Description

Incline Village, NV is an affluent unincorporated community in Washoe County of about 10,000 people located on the northeast corner of Lake Tahoe (Figure 1). The elevation of Incline Village is 6,650 ft and annual precipitation is approximately 18 inches with over 90 inches of snow annually (as measured 10 miles south at Glenbrook, NV) (WRCC 2010). As a result, traction control strategies are an important component of winter driving and include the use of studded snow tires, tire chains, de-icing salt, and road sand. Throughout the winter the major thoroughfares in Incline Village are heavily loaded with traction control material despite Washoe County having reduced the total mass applied by two thirds over the past 5 years (Dick Minto, Washoe County, personal communications). In addition, the Washoe County roads department in Incline Village has for many years been proactive in sweeping roads as soon as they are dry under the assumption that street sweeping improved water quality. The county was interested in supporting a study to determine if their assumption was correct.

This study defined a pair of nested, hydrologically connected study areas (i.e., the discharge of the first study area flowed into the second) on 752 m of a primary county road (Village Blvd.) in Incline Village, NV. This section of Village Blvd. was relatively steep (average slope = 7.3%) with 5 secondary residential streets intersecting it. A stormwater conveyance system was installed the length of the road in 2003 consisting of curb and gutter that directed stormwater to 17 drop inlets. The off-line drop inlets connected to a central conveyance pipe that discharged stormwater to a treatment vault, then to a small settling basin, and finally into Rosewood Creek (see Figure 11). Each 2x3 ft drop inlet had a sump capacity at least 4 ft below the invert of the 12-inch outlet pipe. The 12-inch outlet pipe discharged to a central, 18 to 24-inch diameter concrete conveyance pipe. The effluent from the central conveyance pipe was treated by a hydro-dynamic water quality treatment vault (Contech® CDS®). The road surface was in very good condition (i.e., no pot holes, significant cracks, or patches) having been repaved in 2003 after the stormwater conveyance system was installed.

The Ace Catchment encompassed approximately 35 acres and the Harold Catchment approximately 98 acres. However, runoff from these topographically defined areas have been highly altered by stormwater conveyance systems, residential housing, roads, and curb and gutter. For this study, the runoff from Ace and Harold was measured in the culvert that drains Village Blvd. and was dominated (almost exclusively) by runoff from directly connected impervious surfaces.

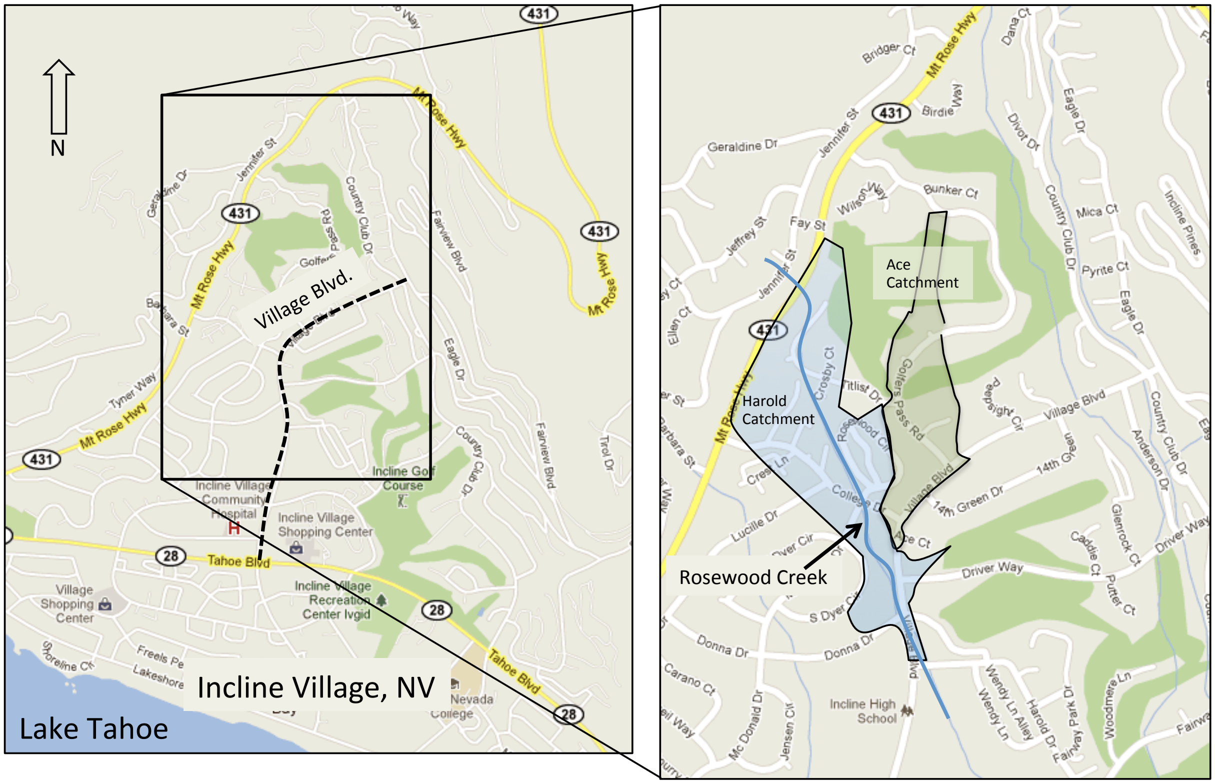

Figure 1. Extent of the topographically defined Ace Catchment (green) and the Harold Catchment (blue).

For the purpose of this study, the “Ace study area” refers to the portion of Village Blvd. within the Ace Catchment that drains to the water quality monitoring system near Ace Court (Figure 10). The “Harold study area” refers to the portion of Village Blvd. within the Harold Catchment that drains to the water quality monitoring system near Harold Drive. The Ace study area was 433 m long with an average slope of 6.9%, a road area of 4,441 m^2, and a southwest aspect. The Harold study area was 319 m long, average slope of 7.9%, a road area of 3,117 m^2, and a south aspect. Draining into the Ace study area were legacy stormwater systems for Golfers Pass consisting of 4 DIs draining an area of 6,478 m^2 and 666 m^2 from College Drive. In addition, other minor drainages (such as driveways and road aprons) contributed to the overall water volume running off Ace and Harold.

The vast majority of the area behind the curb of Village Blvd. was stable and relatively flat. The few cut slope areas were stable and were not observed contributing sediment to the road. Although parking by residents on the pervious area behind the road curb was noted at two locations, this practice was only possible when snow was absent and therefore was not considered a sediment source.

METHODS

This section is divided into two major sections. The first section lays out the methods for sample collection and analysis. The second section lays out the operational methods in which the sample analysis methods were employed.

Sample and Analysis Methods

The sample methods selected for this study were simple and repeatable, and minimized the support required from Washoe County personnel. Most of the methods either used or were based on previously published and proven approaches.

Vacuum

The Simplicity model S36 “true-HEPA” household vacuum was used to sample road sediment (Figure 2). Most studies have used canister-type shop vacuums to vacuum dry road sediment (Rochfort et al. 2007, Deletic and Orr 2005, USGS 2003, USGS 2007, Selbig and Bannerman 2007, Bannerman 1983, and Pitt 1979), and other studies have used wet sampling to collect road sediment (Rochfort et al. 2007, Deletic and Orr 2005). Shop-type vacuums are generally larger than household vacuums, with larger diameter hoses capable of collecting larger material, and configured to move a greater volume of air than household vacuums. However, for this study the authors felt that vacuum performance measured as “sealed pressure,” reported in vertical inches of water, was more important than volume of air because the greater pressure creates more shear stress between the vacuum head and the road surface and therefore was better suited to recover sediment. The Simplicity S36 had a sealed pressure rating of 100 inches whereas a Shop-Vac brand 5-gallon “drywall” vacuum had a sealed pressure rating of 64 inches and the Shop-Vac “professional” series had a rating of 75 inches. In addition, Simplicity vacuum had other advantages including more secure connections between the hose, wand, head, and canister unit, and the option to use a fabric micro-filtration bag.

Figure 2. The Simplicity S36 vacuum cleaner and the 8-inch vacuum head used for this study.

The Simplicity S36 was equipped with two filters: one before the fan assembly and a HEPA filter after the fan. The filter before the fan remained in place throughout the experiment to protect the fan from accidental ingestion of large material, but the HEPA filter was removed to ensure a constant flow of air.

An 8 inch-wide vacuum head was selected that had horsehair brushes in front and back to create a seal between the vacuum head and road. Wheels, 3/4 inch in diameter, were located on either side of the head assembly and allowed the head to move smoothly over the road while maintaining a constant gap to the road. Because the brushes would wear, the head was periodically replaced. Over the course of the two-year study, six identical vacuum heads were used.

Vacuum Samples

A three-ply fabric “micro-filtration” bag was used in the vacuum to collect sediment. To determine if fine sediment escaped the micro-filtration bag, the weight of the HEPA filter, capable of capturing 99.7% of 0.3 μm sediment, was measured before and after sediment was vacuumed. The HEPA filter had no measurable increase in weight. Nevertheless, to avoid the potential that the HEPA filter may occlude the flow of air through the vacuum over the course of the study, the filter was removed.

During the first year, the vacuum bag was weighed after each transect was vacuumed to determine if the distribution of sediment between different transects was consistent (the vacuum bags were always transported in a zip-lock bag) (see Appendix B). This procedure was suspended the second year in the interest of time.

During sample operations, when a bag accumulated approximately 500 g of sediment (one-third full), the bag was replaced. Typically two bags were used per study area before the road was swept, but a single bag was sufficient after the road was swept. When multiple bags were used, the contents were composited to create a single sample for the given study area. In the final tally, sediment from 90 vacuum bags was combined to yield 57 samples for subsequent analysis.

After collection, each bag was dried at 25º C for at least 3 days. The dry sample weight was used in subsequent data analysis. To process the sample, bags were cut open and contents emptied into a 5-gallon bucket. The top was placed on the bucket and the emptied bag shaken using a configuration similar to a butter churn (Figure 3). The sediment was removed from the bucket and dry sieved for 3 - 4 minutes using three 8-inch sieves (Table 1) shaken by a Gilson Company, Inc. model SS-15 sieve shaker. No more than 250 grams of sediment was sieved at a time. The <600 μm sediment fraction was bagged, weighed, and sent to the Desert Research Institute (DRI) for LPSA (see Table 1 for the bin sizes).

Figure 3. The apparatus used to shake the vacuum bags.

Despite vigorous shaking, some fine material remained embedded in the fabric of the bag (averaging 13 ± 7.5 g, n=90). The first 20 vacuum bags, representing 12 samples, were washed to recover as much sediment as possible from each bag. After a bag was shaken, it was cut completely open (Figure 4) and washed by hand with 1 liter of a 5 mg/l solution of sodium lauryl sulfate. The wash water was decanted into a sample jar and another liter of deionized water was added to the bucket (no added sodium lauryl sulfate) and the bag was rinsed. The rinse sequence was repeated three times until a total of 4 liters of water were used. All 4 liters were combined and an aliquot submitted for LPSA. The washed vacuum bags were dried and reweighed. The difference between the unwashed and washed bag weight represented the total sediment mass in the 4 liters of wash water. Washing could not remove all the sediment from the fabric of the bag, but it was assumed the particle size distribution of the wash water was similar to the distribution of the material that remained in the bag. The LPSA results from the 12 samples had very similar distributions and permitted the creation of a “representative distribution” by averaging the 12 LPSA results (Figure 5).

This distribution (Figure 5) indicates 72% of the sediment mass retained by the bag had a diameter of 16 μm or less. For the subsequent 70 vacuum bags, it was assumed that sediment retained by bags conformed to the representative distribution of the first 20 bags. The mass of sediment retained by each vacuum bag was proportionally added to the mass distribution of the >600 μm sieve and <600 μm LPSA data. The sediment mass retained by the vacuum bag was not a significant factor when the sediment sample collected was large, but it was increasingly important when the sample mass was small. As an example, the mass per unit area collected for one small sample increased from 0.05 g/m^2 of <16 μm sediment to 0.37 g/m^2 when the mass of the vacuum bag was added.

LPSA was performed by a Saturn Digisizer laser backscatter system that accurately analyzed size fractions of 600 μm or less. The results of the LPSA analysis, the dry sieve data, and mass of sediment in each vacuum bag were proportionally combined in a spreadsheet.

Figure 4. Three plies in the micro-filtration vacuum bag.

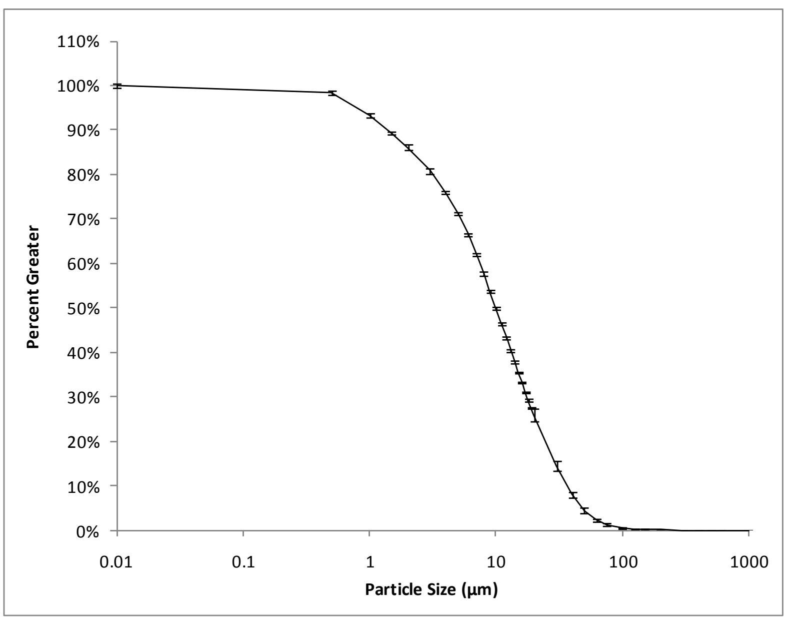

Figure 5. The representative particle size distribution of sediment retained by a vacuum bag (mean particle size is 9.8 μm). The error bars represent one standard deviation for a given bin.

Table 1. Particle sizes in microns sieved and analyzed in the laser particle size analyzer (LPSA).

Dry Sieve	LPSA
2000	
1000	1000
600	600
<600	500
	400
	300
	200
	150
	125
	100
	75
	62.5
	50
	40
	30
	20
	19
	18
	17
	16
	15
	14
	13
	12
	11
	10
	9
	8
	7
	6
	5
	4
	3
	2
	1.5
	1
	0.5
	<0.01

Street Sweeper

Washoe County used a Tennant Sentinel™ street sweeper, a small, four-wheel-steer, mechanical sweeper with vacuum assist (Figure 6) to sweep all county roads in the Lake Tahoe basin. In addition to the gutter brooms commonly found on sweepers, a third articulating broom was located on the front of the sweeper that could sweep sidewalks, the top of curbs, or follow the contours of the street gutter. The three disc brushes directed material to a center, 51-inch wide, cylindrical brush and an elevator that lifted material into a hopper. Simultaneously, a vacuum drew air from around the skirt, through the main hopper, and through a 0.5 μm filter located on top of the hopper.

Material commonly collected from Incline Village streets included pine needles, pine cones, street sediment, and the rare item of trash. Because the Sentinel had a vacuum and filter system, the sweeper did not require water to suppress the entrainment of dust. As a result, the county could sweep the streets during the winter as soon as they were dry regardless of the temperature.

Figure 6. A picture and internal view of the Tennant Sentinel™ street sweeper (www.tennantco.com).

Sweeper Samples

Washoe County personnel ensured the hopper and filter of the street sweeper were clean prior to sweeping the study area. The study areas were swept using the articulating broom to follow the gutter, in which, most of the sediment was located. After the study area was swept, the sweeper would return to the maintenance yard and dump the main hopper (Figure 7). The resulting sediment pile was "squared up" to resemble a trapezoidal prism and the dimensions measured. The street sweeper's internal filter was then shaken resulting in a layer of very fine sediment in the hopper. For the first year, the volume of the coarse and fine sediment was measured separately (the coarse sediment was measured on the ground and the fine sediment in the hopper). Representative samples were collected from coarse and fine material and analyzed separately for particle size. The results for both fractions were proportional combined to produce a size distribution of the bulk (i.e., fine plus coarse) sediment. In the second year, the coarse and fine sediment were dumped into the same pile and homogenized with a shovel. Several subsamples were taken throughout the pile of material and combined in a 500 ml sample bottle to achieve an integrated sample.

The bulk sweeper pile usually contained a considerable volume of pine needles and pine cones. To determine the aggregate density for a typical sweeper load, bulk samples were collected in 5 gallon buckets on 23 Jun 2009 and 23 March 2010 to determine an average bulk density of 1.36 g/cm^3. The sweeper sediment samples were dried, sieved, and the <600 µm size fraction sent to DRI to be analyzed for LPSA (Table 1).

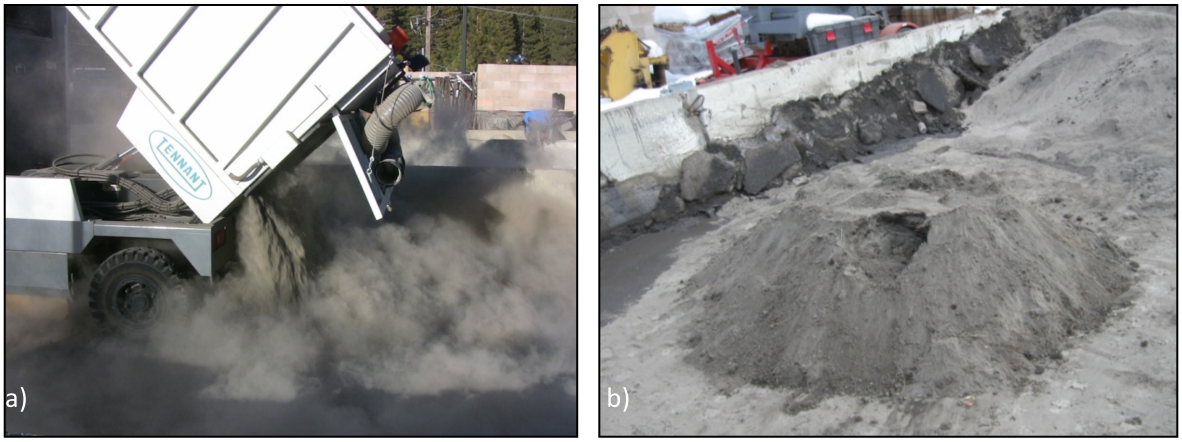

Figure 7. The Tennant Sentinel street sweeper a) dumping sediment and b) the resulting sediment pile.

Drop Inlets

Each of the 17 drop inlets (DIs) had sump volumes (i.e., a volume below the outfall invert) of at least 24 ft^3 (2 ft x 3 ft and at least 4 ft deep). The sumps allowed suspended sediment to settle preventing it from entering the conveyance system and being sampled by the downstream water quality samplers. To estimate the volume and the size distribution of the material captured by the DIs, three DIs were sampled on four occasions. The DIs sampled included one on the north corner of College Drive and Village Blvd. (designated “College”), one on the west side of Village Blvd. across from Ace Ct. (designated “Ace”), and the third on the east side of Village Blvd. just up from Harold Drive (designated “Harold”). The College DI drained a portion of the intersection of College and Village (~120 m^2), but mostly captured water from the northwest side of Village above College (~420 m^2). The College DI also accepted flows from an upstream DI draining an area of approximately 666 m^2 of College Drive. The Ace DI collected water draining from a portion of the apron from College (~50 m^2) and some of the intersection of College Drive and Village Blvd (~170 m^2). The Harold DI captured stormwater from approximately 1,600 m^2 of the east side of Village Blvd. from Driver Way to Harold Drive, a distance of over 244 m. The DIs were selected such that at least one DI from Ace and Harold was sampled and that one DI from the right and left side of the road was sampled.

To sample the DIs, a Dayton Submersible Utility Pump Model 3YU55A (1/4 horse power) was used to decant the standing water from the DI. The first three sets of samples were collected by removing all the material from the DI in 5 gallon buckets, dried in long shallow tubs outside the NTCD offices, homogenized, then a subsample dried in an oven, sieved, then submitted to DRI for LPSA analysis. This procedure, although labor intensive, permitted the measurement of the wet and dry bulk density, as well as, the collection of a well-integrated composite sample. The final set of DI samples involved decanting the standing water out of the DI, then leveling the material in the DI to obtain a uniform depth (from which the volume was calculated), collecting sub-samples from several locations to fill three 500 ml containers, then drying and homogenizing the samples for analysis.

Traction Control
The traction control material used by Washoe County in the Tahoe Basin was supplied by the Nevada Department of Transportation (NDOT). NDOT sand meets following parameters known as specification "D" (Table 2) (NDOT 2007).

Table 2. Range of particle sizes for NDOT Specification D road abrasives.

Sieve	Opening (µm)	Content Range
#4	4760	93%-100%
#8	2380	40%-80%
#16	1190	15%-60%
#50	297	0%--20%
#100	149	0%--4%
#200	74	0%--2.5%

- Durability Index or hardness greater than 75.
- Loss by abrasion less than 33%.
- Maximum phosphorus content less than 10 parts per million.

The NDOT sand was mixed with salt (sodium chloride) at the Washoe County maintenance yard in a 3:1 ratio. Samples were collected at the maintenance facility using a trowel to obtain several subsamples from different locations in the storage facility. The samples were dried, sieved, and analyzed for particle size distribution.

The mass of traction control material applied to the road was determined by Washoe County road maintenance personnel. Each "sand" truck used a mechanized spreader calibrated to apply 1.4 kg of traction control material per second. The spreader was activated by the driver in the cab of the vehicle. The mass applied was determined by recording the duration the spreader was active in the study area. The mass applied during the first year was reported for the entire study area. During the second year the mass was reported separately for Harold and Ace.

Washoe County applied traction control material to those road areas prone to safety issues. As a result, traction control was generally only applied in and near intersections. In the context of this study, sand was applied primarily at the intersection of College Drive and Village Blvd., but the intersections of Village Blvd. with Golfers Pass, Driver Way, and Donna Drive were also sanded on occasions.

Water Quality
Continuous turbidity, conductivity, and temperature were collected at both sample sites (Figure 8). Autosamplers (Isco model 6712 at Harold and Isco model 3700 at Ace) collected discrete samples from the stormwater runoff when the stage and rate of change of turbidity exceeded a threshold. The autosamplers continued sampling until both the stage and turbidity receded below threshold values. The samples were proportionally composited and concentrations determined as an event mean. Water quality samples were not frozen and were analyzed within 48 hrs unless otherwise noted. Samples for total suspended sediment (TSS) and LPSA were refrigerated at 4 C^{o} and analyzed when convenient. Tabletop turbidity measurements were collected for most samples.

Discharge
Palmer-Bowlus (PB) flumes were installed to quantify water discharge at Harold and Ace sites (Figure 8). This type of flume was chosen as it could be installed through a manhole and because it was self-cleaning and unlikely to plug the culvert system during a large runoff event. A 12-inch PB insert flume was installed in the culvert at Ace through a manhole access. A 10-inch 4xD PB flume was installed in the Harold vault antechamber so that water exiting the culvert was directed through the flume prior to entering the cyclonic treatment section of the vault. The flumes were installed in a grout bed utilizing standard flume installation practices. A stilling well was attached to factory-installed pass-throughs at Harold. At Ace, the level sensor was installed immediately behind the flume in the approach section. Discharge was calculated using a rating table that converted stage measured by calibrated pressure transducers into discharge.

Two other flows were conveyed into the Ace study area that included 666 m^2 of College Drive and 6,478 m^2 of Golfers Pass. An unsuccessful attempt was made to measure flow from Golfer's Pass and as a result, stormwater from College Drive and Golfer's Pass was not quantified.

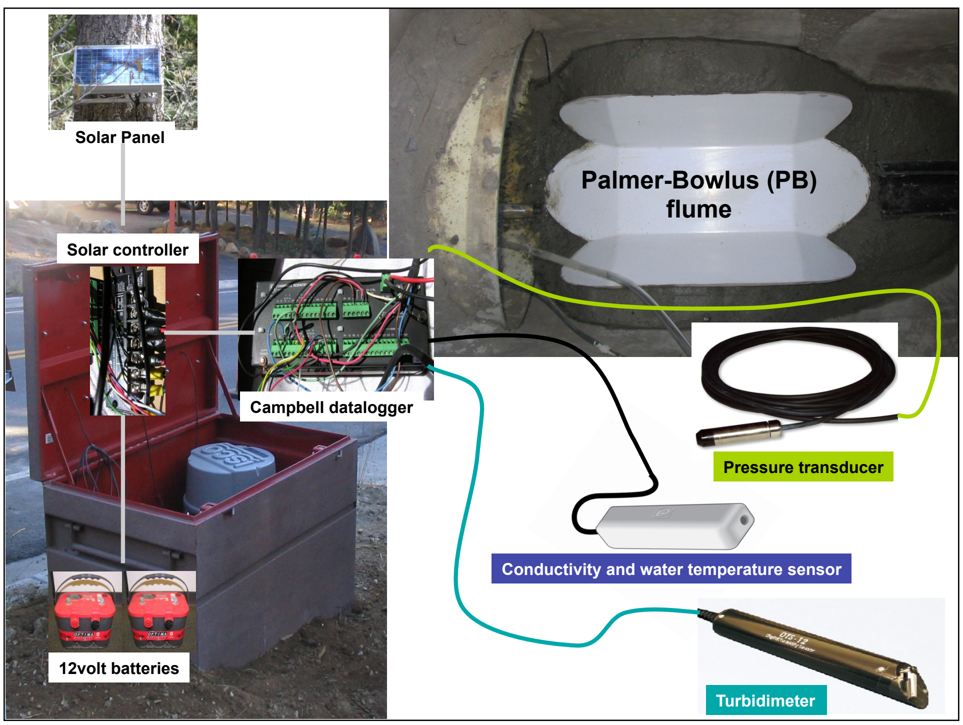

Figure 8. Schematic of the water quality sampling configuration used for the sweeper study.

Traffic Volume
Traffic volume, as noted in the introduction, is a critical component in the mass per unit area and transformation of particle size. Traffic volume was measured in the Harold study area on three occasions and once in the Ace study area using a TimeMark Inc. Gamma pneumatic tube system (Figure 9). The data were collected over a five to nine day period in early summer when there was little risk of a snowplow or sweeper damaging the tubes.

Figure 9. Traffic tubes on Village Blvd.

Operational Methods

This section lays out the procedure or sequence used to collect the data and samples explained above.

Vacuum Transects

Ten permanent transects were defined in the study area…five in each study area (Figure 10) spaced as evenly as possible along the study area. Each transect was divided into an A and B-side, 10 ft apart, and of equal length (except for the "intersection" transect). Nine of the transects were perpendicular to the curb. The "intersection" transect was established diagonally across the intersection of College Drive and Village Blvd. in an attempt to collect a representative sediment sample through this major intersection. The intersection transect had an A and B-side of unequal lengths and the transect was not perpendicular to the curb (Figure 10).

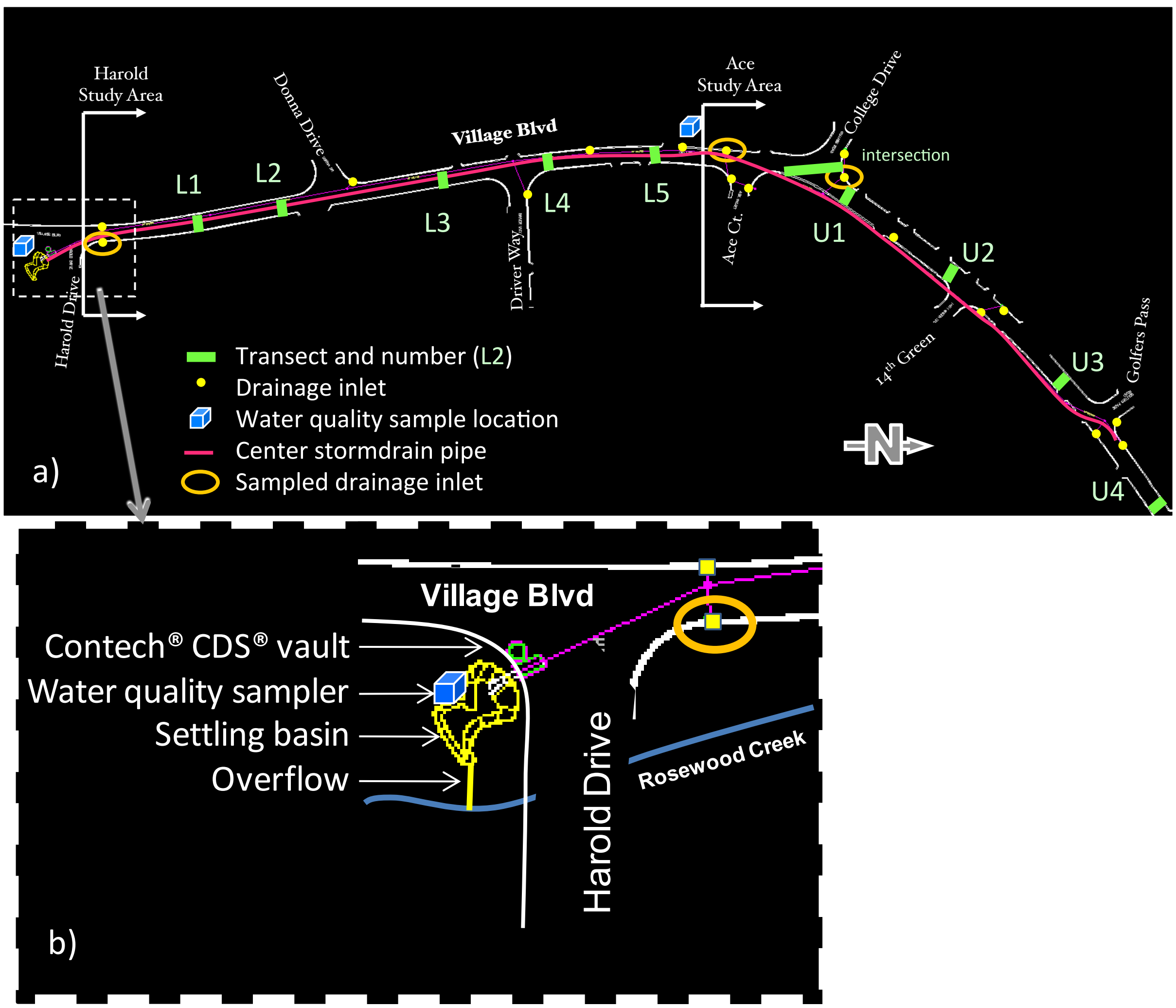

Figure 10. Plan view of the overall sweeper study area (a) and of the outfall of the stormwater system (b).

Functionally, the study areas were arranged as shown in Figure 11. Precipitation on Ace would flow along the curb and gutter to a drop inlet then through a pipe to the central conveyance system, to the outfall treatment systems, then to Rosewood Creek. Flow and associated constituents were sampled before treatment in the hydro-dynamic separator or the detention basin, however, some treatment (or capture) of stormwater sediment occurred in the sump area of the drop inlets.

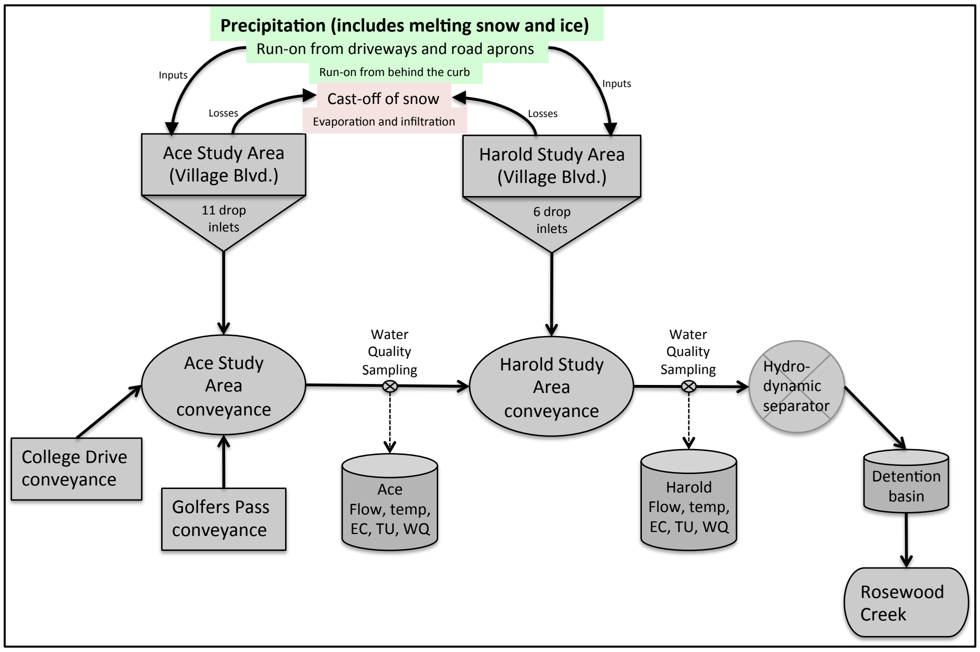

Figure 11. A functional schematic of stormwater inputs to the two study areas. All stormwater was discharged to Rosewood Creek.

The operational procedure of vacuuming a transect involved first randomly selecting the A or B-side of the transect. Second, the vacuum and a 1000 watt Honda generator were mounted on a hand cart and one individual would push the cart while another vacuumed a single 8 inch-wide pass from one curb to the other (Figure 12). The velocity of the vacuum head across the road was held as constant as possible at approximately 6 inches per second (see Appendix B). After all ten transects were sampled on the same side (i.e., A or B), the street sweeper would make multiple passes to sweep the entire width of the road consistent with standard Washoe County practices. Finally, the opposite side of the transect (e.g., B or A) would be vacuumed.

Assuming the average sediment mass per unit area found in the 8 inch-wide transects were representative of the sediment mass per unit area and particle size distribution throughout the entire study area, then the *difference* in sediment mass per unit area vacuumed *before* and *after* the road was swept, should be equivalent to the sediment mass per unit area collected by the sweeper.


Figure 12. Vacuum operations on Village Blvd.

Routine Operational Procedure

Vacuum-sweep-vacuum sampling was ideally scheduled when the road was completely dry (allowing the road to be vacuumed curb to curb) and immediately before the next precipitation event (to maximize the benefit of road sweeping on stormwater runoff). Most road sediment samples were collected during the winter when road abrasives were typically present and the vast majority of precipitation occurred. However, ideal sample conditions were rare because the curb was chronically wet during the winter due to snowmelt. In addition, scheduling was complicated by frequent snowfall, unscheduled sweeper maintenance, and Washoe County's Monday through Thursday work schedule. In spite of the compressed workweek, personnel at Washoe County Tahoe Roads Department were very responsive in scheduling the sweeper and traffic control support. A typical data collection effort would require approximately 4 hours to complete.

When snow or melt water covered sections of the road, only the dry areas were vacuumed and swept (Figure 13). No effort was made to estimate the area of the road not swept, but the length of a transect that could not be vacuumed was measured. The fraction of all the transects that could not be vacuumed was assumed to be representative of the area of the road that could not be swept.

Figure 13. Snow in the curb and water on the road prevented curb-to-curb samples.

To mitigate the possibility of track-in immediately above or below the study area, the swept area was extended beyond the hydrologic boundaries (consistent with ETVC 2006 and Waschbusch 2003). Combined with the logistics of turning the street sweeper around and to simplify the instructions to the maintenance personnel, the actual area swept for the Harold study area extended from Ace Court down Village Blvd. to Northwood Blvd. The Ace study area extended from Ace Court up to Country Club Drive (Figure 14). The fundamental assumption (visually assessed) was that the road sediment load was relatively uniform inside and outside the study area along Village Blvd. The total mass collected was proportionally scaled to compensate for the additional area swept. In November of each year, Washoe County cleaned the DIs and swept the road to ensure the sample operations started from the same baseline.

Data collection for Water Year (WY) 2009 was performed identically on the Harold and Ace study areas, meaning both were vacuumed and swept on the same date. The consistency of the results validated the sampling and analysis approach and led to a more ambitious sample configuration the second year. During WY10, only one study area was swept and the other remained unswept. At mid-winter the practice was reversed. So from 6 January 2010 through 24 March 2010, only the Harold study area was swept. That is, Harold was subjected to the standard vacuum-sweep-vacuum sequence while Ace was only vacuumed to characterize the current sediment mass per unit area. The washoff experiment on 22 March 2010 culminated the Harold-swept, Ace-unswept regime, after which Ace was subjected to the standard vacuum-sweep-vacuum sequence while Harold was only vacuumed to characterize the current sediment mass per unit area. The 1 June 2010 washoff experiment culminated sampling for the entire study (see Table 6 in the Results section for a summary of the sweeper events).

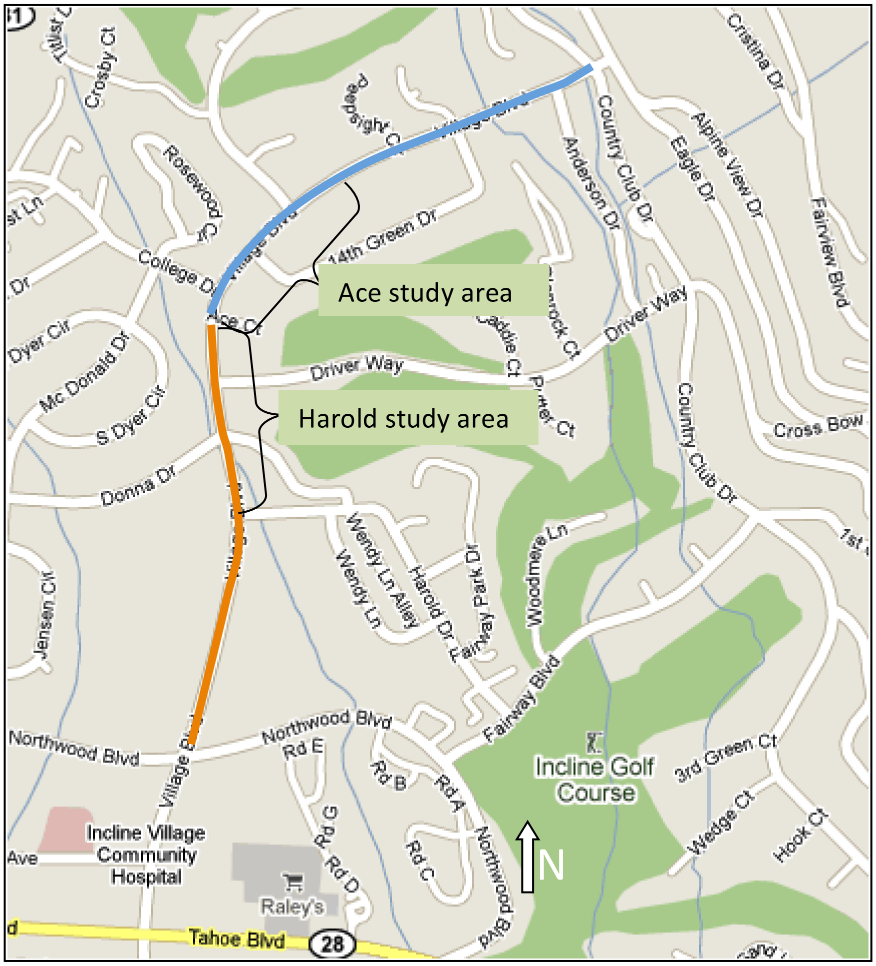

Figure 14. Length of street swept for Harold (orange) and Ace (blue) to prevent track-in to the sample study areas.

Washoff Experiment

During the study it became clear that input to the stormwater samplers needed to be more constrained to determine if street sweeping improved water quality. The solution was named a "washoff experiment" and two were conducted in spring of 2010. Washoe County used a 2,000-gallon water truck to apply potable water the length of each study area (Figure 15). The truck had the capability of using any combination of two spray nozzles in front, two in back, and a gravity dump from under the truck. The goal was to apply 0.5 inch of water on each study area over 2 hours…first on the Harold study area with water quality samples collected at Harold, then once flow ceased, the procedure was repeated on the Ace study area with flow measured and stormwater samples collected at both Ace and Harold. There was no pretense that the water discharge from the truck approximated a rain event; the intense periodic discharge using pressurized spray nozzles was very artificial and likely exceeded a "worst case" thunderstorm scenario.


Figure 15. The Washoe County 2,000 gallon water truck discharging on Village Blvd. during a washoff experiment.

Approximately 10,000 gallons or 5 loads from the water truck were discharged on Harold and 12,000 gallons or 6 passes on Ace were required to achieve the half-inch of water on Ace. The experiments were conducted on 22 March 2010 and 1 June 2010. Various discharge combinations of sprayers and gravity dump were used on the truck until the correct rate was found. When the spray nozzles were used, water was not sprayed outside the curb.

The procedure used on 22 March was to fill the truck at the hydrant on Ace Ct. then discharge the water during a single trip from Ace Ct. to Harold Drive and back while maintaining a constant speed (or from Ace Ct. to the top of the Ace study area and back). It was found that a single round trip with the water truck generated very high peak flows and resulted in 10,000 gallons being discharged in 70 minutes at Harold. A slower discharge rate was used for the 1 June washoff experiment by traveling *two* full circuits of Village Blvd. for each study area to empty the water truck.

In order to collect water quality samples from the flashy washoff flows, the frequency of the samples collected by each auto sampler was increased and these samples were augmented by additional grab samples collected at the flumes. The automated and manual samples were combined to produce a single composite sample.

The operational sequence for the 22 March event for the Harold and Ace study areas is shown in Table 3. Table 4 shows the operational sequence of the 1 June washoff experiment.

Table 3. Sequence of actions for the 22 March 2010 washoff experiment.

Date	**Study Area**	**Action**	**Reason**
22 March	Harold	Vacuum	Determine initial mass per unit area
22 March	Harold	Sweep	Collect material from the road using the Tennant Sentinel street sweeper
22 March	Harold	Vacuum	Determine the mass per unit area remaining on the road and calculate the efficiency of the street sweeper
22 March	Harold	Washoff	Apply water to Village Blvd. in the Harold study area and measure the water quality at the Harold WQ site. The water truck discharged a full load of 2,000 gallons from Ace Ct. to Harold Dr. then back to Ace Ct.; five truck loads were discharged for a total of 10,000 gallons
22 March	Harold	Vacuum	Determine the mass per unit area remaining of the road and calculate the impact of the washoff on mass and particle size distribution
22 March	Ace	Vacuum	Determine initial mass per unit area
22 March	Ace	Washoff	Apply water to Village Blvd. in the Ace study area and measure the water quality at the Ace and Harold WQ site. The water truck discharged 2,000 gallons from Ace Ct. to the top of the Ace study area then back to Ace Ct.; six truck loads were discharged for a total of 10,000 gallons
24 March	Ace	Vacuum	Determine the mass per unit area remaining of the road and calculate the impact of the washoff on mass and particle size distribution
24 March	Ace	Sweep	Prepare for Ace to be the “swept” study area in subsequent sampling during the next two months
24 March	Ace	Vacuum	Determine mass per unit area after sweeping and establish initial conditions

Table 4. Sequence of actions for the 1 June 2010 washoff experiment.

Date	Study Area	Action	Reason
1 June	Harold	Vacuum	Determine initial mass per unit area
1 June	Harold	Washoff	Apply water to Village Blvd. in the Harold study area and measure the water quality at the Harold WQ site. The water truck discharged 2,000 gallons from Ace Ct. to Harold Dr. to Ace Ct. to Harold Dr. back to Ace Ct. (2 circuits of the Harold study area); a total of 10,000 gallons was discharged.
1 June	Harold	Vacuum	Determine the mass per unit area remaining of the road and calculate the impact of the washoff on mass and particle size distribution
1 June	Ace	Vacuum	Determine initial mass per unit area
1 June	Ace	Sweep	Collect material from the road using the Tennant Sentinel street sweeper
1 June	Ace	Vacuum	Determine the mass per unit area remaining on the road and calculate the efficiency of the street sweeper
1 June	Ace	Washoff	Apply water to Village Blvd. in the Ace study area and measure the water quality at the Ace and Harold WQ site. The water truck discharged 2,000 gallons during 2 circuits of the Ace study area; a total of 12,000 gallons was discharged.
2 June	Ace	Vacuum	Determine the mass per unit area remaining of the road and calculate the impact of the washoff on mass and particle size distribution

RESULTS

For this report, “sweep” is defined as road sediment collected by the county street sweeper, whereas “vacuum” is road sediment collected by the vacuum cleaner. Results are generally reported in mass per unit area (referred to in graphs and tables as “yield”). The results section concludes with a summary of the washoff experiment that interleaves sweeper, vacuum, and runoff data.

Chronology

To better appreciate the context of the data that is presented in the following sections, a chronology of samples and precipitation is provided in Figure 16 and in a narrative format in Appendix C. Figure 16 presents a hyetograph and snow depth data (WY09 only) collected from the Diamond Peak Ski Resort located 1.5 miles east and 120 feet higher in elevation than the study areas. Because precipitation was primarily snow during the winter, a decrease in snow depth may be a better indication of a runoff event in the study areas. The collection dates for water quality, sweeper, and vacuum samples are indicated by vertical lines. The *scaled* mass of traction control applied is graphed, along with the *scaled* results from water quality samples (TSS and fine sediment). Finally, some key operational notes are included; for example, the authors are confident the study areas did not experience precipitation between 12 Jan and 20 Jan 2009 whereas Diamond Peak Ski Resort reported precipitation.

Traffic Count

The results for the two traffic counts in 2009 are consistent (Table 5), but the single count in 2010 indicates a 33% increase in traffic from the previous year. There was no obvious reason for the increase. The 2010 data was collected on Village Blvd. in both study areas—in the Harold study area (below College Drive) and in the Ace study area (above College Drive). The seven-day daily average for the 2010 data was 1914 and 735 on Harold and Ace, respectively, and reveals about 60% of the Harold traffic diverts to/from College Drive (presumably as a shortcut to SR 431).

Table 5. Average traffic count data for Harold and Ace. Uncertainty values for the weekend traffic counts were not calculated because of sample size (n=2).

	Harold		Ace	
Dates	Weekday	Weekend	Weekday	Weekend
24 to 28 June 2009	1518 ± 71	1260		
8 to 16 July 2009	1557 ± 49	1214		
15 to 21 June 2010	2080 ± 55	1499	801 ± 25	570

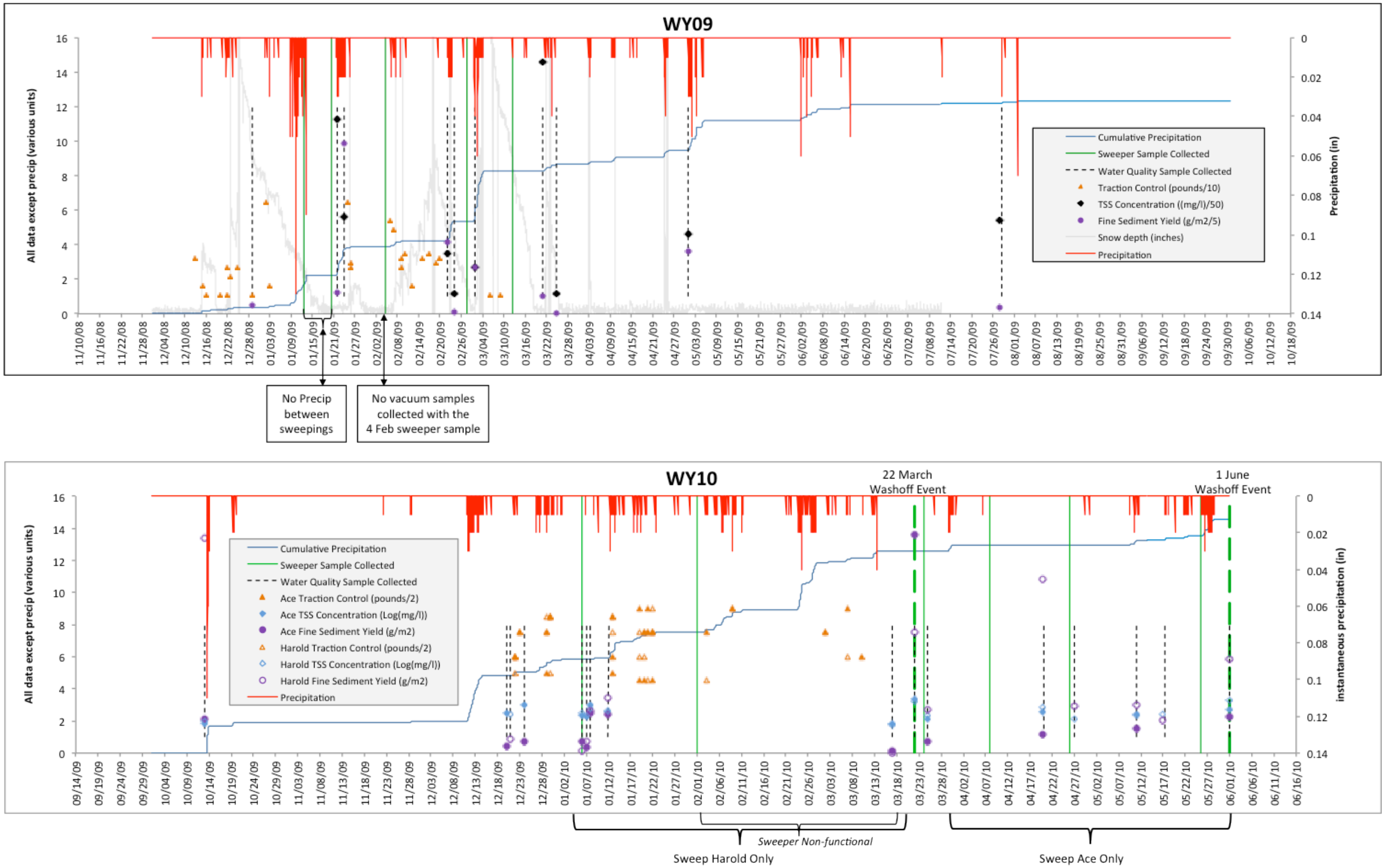

Figure 16. Chronology of events in WY 2009 and 2010. Note that many data points have been scaled to fit the range of the Y-axis (see the respective legends). “Fine Sediment Yield” is the fine sediment mass from stormwater runoff normalized to road area.

Traction Control Material

Two traction control samples were analyzed for particle size distribution (Figure 17) and nutrients. The fraction of <75 μm material averaged 2.6% which may have exceeded the NDOT specification of 2.5% for <74 μm. The sub 16 μm fraction averaged 1.2% (Table 6). Total phosphorus (TP) concentration averaged 839 mg/kg far exceeding the 20 ppm (mg/kg) specification set by NDOT. However, this study used a total digestion method to determine TP, but it is not clear with which method NDOT intended samples to be analyzed. It should be noted that soluble reactive phosphorus was not elevated in stormwater samples analyzed for this study.

Washoe County applied 333 and 286 kg of traction control material WY 2009 and 2010, respectively (Table 7). It is possible an additional small amount of material was not included in the WY10 total because the computer files compiling the data were lost after 7 March 2010. However, the maintenance supervisor for Incline Village Roads department does not believe additional material was applied the remainder of the winter months.

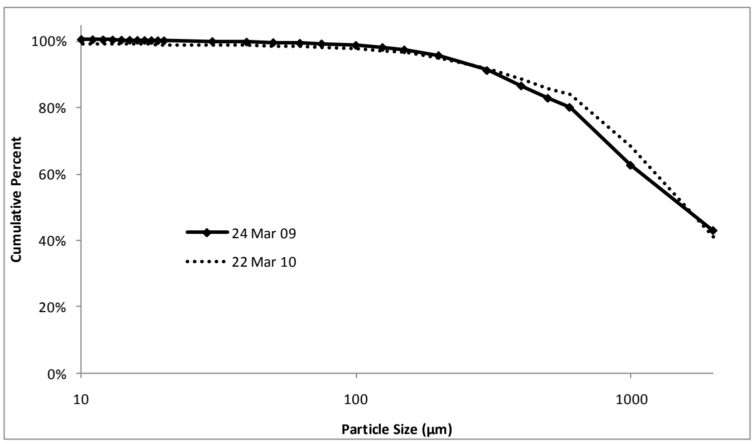

Figure 17. Traction control size distribution for two samples.

Table 6. Percent composition of traction control material for specific size fractions.

	<75 μm	<16 μm
22-Mar-09	2.9%	1.4%
24-Mar-10	2.3%	1.0%
Average	2.6%	1.2%

Table 7. Mass in kilograms of traction control material applied during the study period by year and study area. The <16 μm mass was estimated using the values in Table 6.

WY	Study Aea	Combined	Sand	Salt	<16 μm Sand
2009	Both	333	250	83	3.0
2010	Ace	147	110	37	1.3
	Harold	140	105	35	1.2
	Total	286	215	72	2.6
	Overall Total	619	465	155	5.5

Sweeper Samples

Fourteen sweeper events were analyzed: 6 in the first year encompassing the entire study area, and 8 the second year encompassing either the Harold or Ace study area individually. Overall, the mass distribution by particle size shows 5.7% of the material collected by the sweeper was less than 16 µm. In terms of mass, 9 metric tons were collected in 14 sweeper loads, 530 kg of was <16 µm (Table 8).

The first sweeper event occurred on 12 Jan 09 after significant snowstorms the previous weeks. After the road was swept, the sweeper was emptied, and the street was swept again. This was the only sample event where the study areas were swept twice. The second pass collected only 11% of the mass collected the first time and Figure 18 shows the particle size shifted to more fine material.

Table 8. Mass of material collected by the street sweeper in the study area for the entire study period. Yield is the average sediment per unit area for the date or period.

	Volume (m^3)	Mass (kg) Total	Mass (kg) <16 µm	Yield (g/m^2) Total	Yield (g/m^2) <16 µm	% <16 µm
12 Jan 09 A	0.77	1041	75	138	9.9	8.7%
12 Jan 09 B	0.09	116	14	15	1.8	13.8%
20 Jan 09	0.17	231	10	31	1.3	5.0%
4 Feb 09	1.13	1536	79	203	10	6.5%
27 Feb 09	0.31	416	9	55	1.2	3.4%
12 Mar 09	0.19	259	10	34	1.3	5.3%
WY09 Summary	*2.6*	*3600*	*196*	*79*	*4.3*	*5.5%*
6 Jan 10 Harold	0.27	364	23	117	7.3	7.0%
1 Feb 10 Harold	0.39	524	36	168	11	7.7%
22 Mar 10 Harold	1.87	2538	150	814	48	6.5%
24 Mar 10 Ace	1.05	1425	81	321	18	6.3%
8 Apr 10 Ace	0.17	235	14	53	3.2	6.7%
26 Apr 10 Ace	0.22	303	13	68	2.8	4.6%
25 May 10 Ace	0.14	188	12	42	2.6	6.9%
1 Jun 10 Ace	0.05	73	5	16	1.2	8.4%
WY10 Summary	*4.2*	*5650*	*333*	*179*	*11*	*5.9%*
Study Total	**6.8**	**9250**	**530**	**120**	**6.9**	**5.7%**

Between the 12th and 20th of Jan, there was no precipitation and no traction control material applied. On 20 Jan 2009, just before the next storm, the road was swept. The sediment collected on 20 Jan was composed of a smaller fraction of fines than the 12 Jan samples (Table 8 and Figure 18). This may have occurred because the dry conditions were ideal to entrain the fines into the atmosphere leaving the coarse fraction on the road. The study area was next swept on 4 Feb collecting 1,536 kg of material, nearly as much material as the other four sweepings combined (but no vacuum samples were collected).

For WY10, the Harold study area was swept three times and Ace five times. Persistent ice and snow, and mechanical issues with the sweeper, prevented more frequent sweeping of Harold the first half of the winter. On 22 March, seven weeks after it was last swept, Harold was swept curb to curb collecting 1.87 m^3 of material, easily the largest volume collected during the study (Table 8). During the second half of the winter (i.e., after 22 Mar) only Ace was swept.

Approximately 57% more material was collected from the study areas in WY10 than WY09 despite less traction control being applied and less total area being swept. This difference may be partially due to a chip seal operation on College Drive just prior to the onset of winter in 2010.

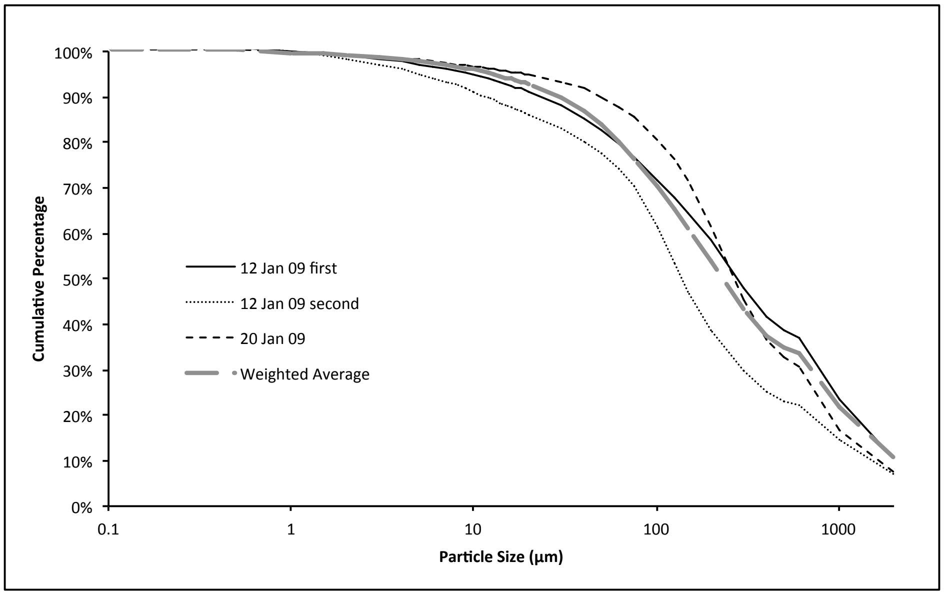

Figure 18. Particle size distribution of the first three sweeper samples and the mass weighted average of all sweeper samples collected for the study.

Vacuum Samples

The results of the 34 sets of vacuum data are presented in Table 9. The difference between the “before” sample and the “after” sample indicates the mass of sediment removed by the street sweeper (the single exception is the 12/16 October 2009 sample set which reflects the effects of a large rain event, no sweeping). Because of chronic melt water on the road, the transects could not be consistently vacuumed curb to curb. The average length of the transects available to vacuum (i.e., dry sections of road) are presented as “percent vacuumed” in Table 9.

The average sediment mass per unit area on the road before sweeping was variable, 91 ± 66 g/m^2 and 7.8 ± 4.5 g/m^2 for total and <16 µm sediment, respectively, yielding coefficients of variation (CVs) of 72% and 58%, respectively. After the road was swept, the average sediment remaining on the road was more consistent at 21 ± 6.2 g/m^2 and 4.3 ± 1.4 g/m^2 for total and <16 µm, respectively, yielding CVs of 29% and 33%, respectively. The relative consistency of sediment mass remaining on the roadway after the sweeper was used supports the conclusion in Pitt (1979) that there is a base mass per unit area of sediment on the road that sweepers are unable to collect. Specifically regarding fine sediment, Table 9 shows 3.3 g/m^2 is the lowest mass per unit area the sweeper can achieve in the winter, but the Oct 2009 event shows that rain is capable of reducing fine sediment mass per unit area to 0.4 g/m^2. Finally, the overall fraction of fines was 8.1% before sweeping, but 20% after sweeping indicating the sweeper removed more coarse sediment than fine.

Table 9. Road sediment mass per unit area reported in coarse and fine fractions. "Before" indicates initial conditions. "After" signifies a vacuum sample after sweeping.

	Yield (g/m^2) Total	Yield (g/m^2) <16 µm	% <16 µm	% vacuumed
12 Jan 09 Ace Before	83	9.7	12%	87%
12 Jan 09 Ace After	28	7.1	25%	82%
12 Jan 09 Harold Before	127	15.8	12%	86%
12 Jan 09 Harold After	13	3.3	26%	89%
20 Jan 09 Ace Before	28	3.5	13%	84%
20 Jan 09 Ace After	17	3.3	19%	84%
20 Jan 09 Harold Before	22	3.3	15%	89%
20 Jan 09 Harold After	15	3.3	23%	89%
27 Feb 09 Ace Before	79	8.1	10%	79%
27 Feb 09 Ace After	25	4.9	20%	81%
27 Feb 09 Harold Before	155	14.4	9%	91%
27 Feb 09 Harold After	30	7.0	23%	90%
12 Mar 09 Ace Before	74	8.4	11%	88%
12 Mar 09 Ace After	23	5.4	23%	82%
12 Mar 09 Harold Before	109	8.8	8%	85%
12 Mar 09 Harold After	18	3.9	22%	83%
12 Oct 09 Ace Before	38	1.4	4%	100%
16 Oct 09 Ace After_rain	19	0.5	3%	100%
12 Oct 09 Harold Before	32	1.1	3%	100%
16 Oct 09 Harold After_rain	14	0.4	3%	100%
6 Jan 10 Harold Before	97	6.8	7%	43%
6 Jan 10 Harold After	15	3.6	25%	42%
1 Feb 10 Ace Before	88	8.4	10%	72%
1 Feb 10 Harold Before	109	7.9	7%	87%
1 Feb 10 Harold After	19	4.0	21%	89%
22 Mar 10 Harold Before	288	17	6%	94%
22 Mar 10 Harold After	23	5.8	25%	99%
24 Mar 10 Ace Before	106	5.7	5%	99%
24 Mar 10 Ace After	25	2.9	12%	99%
8 Apr 10 Ace Before	70	5.1	7%	93%
8 Apr 10 Ace After	22	4.0	18%	92%
8 Apr 10 Harold Before	87	5.8	7%	94%
26 Apr 10 Ace Before	48	4.6	10%	99%
26 Apr 10 Ace After	34	4.9	15%	99%
26 Apr 10 Harold Before	143	7.8	5%	100%
25 May 10 Ace Before	41	3.8	9%	100%
25 May 10 Ace After	19	3.3	17%	100%
25 May 10 Harold Before	131	7.6	6%	100%
1 Jun 10 Ace Before	18	2.1	11%	100%
1 Jun 10 Ace After	14	2.2	15%	100%

Winter Vacuum Results

Table 10 summarizes the results for 2009 and 2010 and reveals that 3,735 kg of sediment was removed by the street sweeper over the two year study. Figures 19 and 20 show the percent of sediment removed by particle size from both Ace and Harold for the four vacuum-sweep-vacuum events in the winter of 2009. The distribution of sediment removed from Harold on 12 Jan (solid, black line in Figure 19) indicates approximately 80% of all particle sizes were removed from the road including up to 97% of larger size fractions. In contrast, the Ace sample from 12 Jan (dashed, black line) shows fine sediment removal was much less successful. In fact, for all but the 20 Jan sample, the sweeper was more successful removing sediment from the Harold study area than from Ace. This is likely because the antecedent moisture on the road surface at Harold was less than at Ace because of Harold's more direct sun exposure, resulting in drier sediment that was less likely to adhere to the road.

The 20 Jan sample was unique in that the sample was collected a week after the road had been swept twice on 12 Jan and no snow had fallen and no traction control material had been applied since. Notice that the fine sediment mass per unit area after sweeping was consistent on Harold and Ace at 3.3 g/m^2. Figure 19 shows the percent reduction for all particle sizes on Ace for 20 Jan was greater than Harold likely due to higher initial mass per unit area and a week of dry conditions that enhanced sediment removal on Ace.

The Figure 19 also shows that some particle sizes on Harold on 20 Jan *increased* as a result of sweeping. Possible reasons for the perception of an increase in fines include: a) the physical action of the sweeper redistributed sediment across the road making more fines available for vacuuming, and/or b) larger sediment that armored fine sediment was removed making more fines available for vacuuming (observed by Burton and Pitt 2002). Overall, the winter 2009 vacuum samples show 47% of the <16 μm sediment was removed from the road by street sweeping.

Table 10. Sediment reduction calculated from the difference between “before” and “after” vacuum samples. The sediment was removed by the street sweeper (not rain or washoff). The “2009 Overall,” “2010 Overall,” and “Study Total” reflect the *average* “Yield Reduction,” but the *sum* of “Mass Removed.”

	Pecent Reduction		**Yield Reduction (g/m^2)**		**Mass Removed (kg)**	
	Total	**<16 μm**	**Total**	**<16 μm**	**Total**	**<16 μm**
12 Jan 2009 Ace	71%	27%	52	2.6	230	11
12 Jan 2009 Harold	91%	79%	102	12.5	317	39
20 Jan 2009 Ace	44%	6.7%	11	0.24	48	1.1
20 Jan 2009 Harold	38%	-1.6%	6.9	-0.05	21	-0.17
27 Feb 2009 Ace	73%	39%	52	3.1	230	14
27 Feb 2009 Harold	83%	52%	117	7.4	365	23
12 Mar 2009 Ace	73%	35%	48	3.0	211	13
12 Mar 2009 Harold	86%	56%	86	4.9	269	15
2009 Overall	**75%**	**47%**	**56**	**3.9**	**1692**	**117**
6 Jan 2010 Harold	88%	47%	80	3.2	248	10
1 Feb 2010 Harold	85%	50%	86	3.9	269	12
22 Mar 2010 Harold	94%	66%	254	11.0	790	34
24 Mar 2010 Ace	78%	49%	78	2.8	348	13
8 Apr 2010 Ace	73%	22%	47	1.1	209	5.0
26 Apr 2010 Ace	33%	-6.5%	14	-0.30	64	-1.3
25 May 2010 Ace	59%	15%	22	0.56	97	2.5
1 Jun 2010 Ace	25%	-5.1%	4	-0.11	18	-0.47
2010 Overall	**78%**	**42%**	**66**	**2.4**	**2043**	**75**
Study Total	**77%**	**45%**	**61**	**3.1**	**3735**	**192**

The winter 2010 data was not collected in Ace/Harold pairs because only one study area was swept while the other study area was used as a “control.” Figures 19 and 20 show the sediment reduction for winter 2010 vacuum-sweep-vacuum events. As before, more coarse sediment was removed than fine sediment, and more sediment of every size class was removed from Harold compared to Ace. The 100% removal of the 500 μm particle size shown in Figure 19 is assumed to be an anomalous artifact of the LPSA analysis. The negative results of the 26 Apr event suggest sweeping increased the fine sediment mass on the road, but possible explanations for this are listed in the previous paragraph. Overall, 78% of the total and 42% of the fine sediment was removed by street sweeping in 2010.

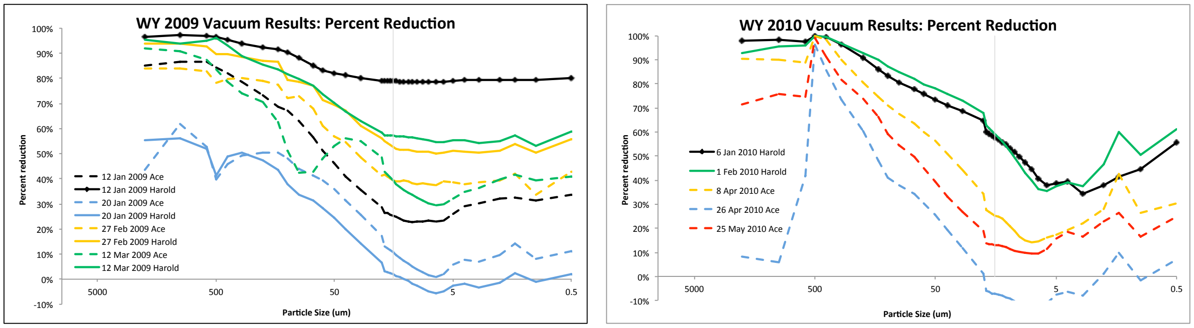

Figure 19. Percent reduction of road sediment for vacuum samples resulting from sweeping Village Blvd for either the Ace of Harold study area for WY09 and 2WY10. The markers on the solid black curves denote each bin size analyzed. The 16 μm bin is denoted by the vertical grey line.

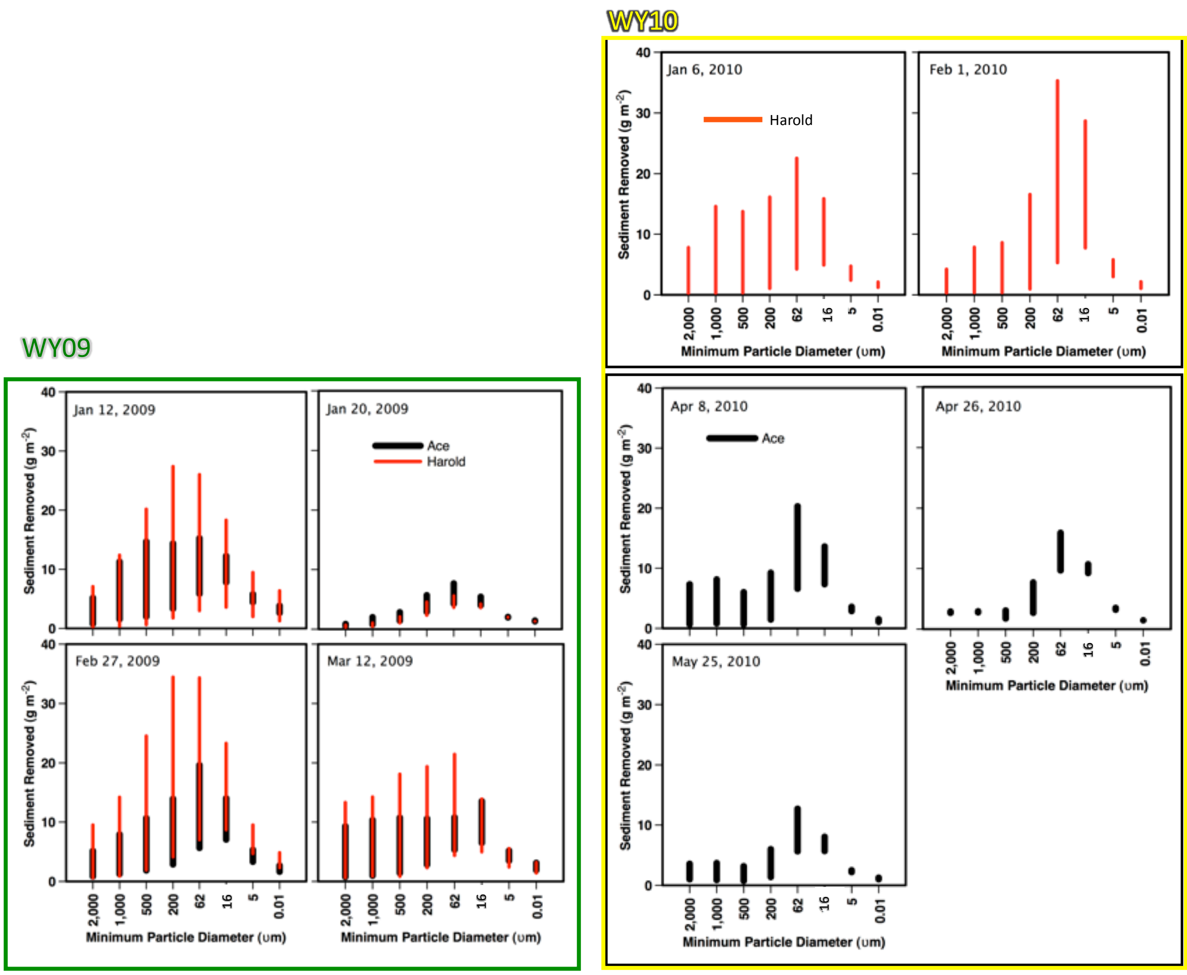

Figure 20. Sediment mass per unit area for Ace (thick black lines) and Harold (thin red lines) for the four vacuum-sweep-vacuum samples in WY09 (green box) and WY10 (orange box). The top of each line represent the mass per unit area of sediment prior to sweeping and the bottom of each line represents the mass per unit area that remained after sweeping.

During WY09, the mass collected by the vacuum from each transect was recorded. By comparing these data, the longitudinal spatial distribution of sediment in the study areas could be determined (i.e., was there a trend of which transect had the most or least mass per unit area for each transect?). The mass per unit area for each study area was rank ordered (1 to 5) for each of the 5 transects for each sample set (e.g., 12 Jan, 20 Jan, etc). For example, Harold's five transects, L1 through L5 (see Figure 10), were assigned a rank (5 for the greatest mass per unit area, 1 for the least) for the 12 Jan 09 "before" data set. Ace's transects were labeled: "intersection" and U1 through U4 (see Figure 10). The "before" and "after" rankings for each of the four sample dates were averaged. The results (Table 11) show the transects nearest the intersection of Village Blvd. and College Drive were on average ranked highest (i.e., L5 and U1). However, "intersection" was not ranked high. The range of ranking for Harold was greater than Ace, and Harold had a more distinct trend of a lower rank with distance from the intersection.

Table 11. Average rank order of transects for each study area for winter 2009 vacuum samples. Lower "Avg. rank" indicates less mass per unit area.

Harold		Ace	
Transect	Avg. rank	Transect	Avg. rank
L1	1.75	U2	2.25
L3	2.88	intersection	3
L2	3	U3	3
L4	3	U4	3.25
L5	4.38	U1	3.5

Summer Vacuum Results

Vacuum samples were collected on 12 and 16 October to characterize the sediment removed by a 33 mm rain event on 13 Oct 09. The study areas had not experienced significant precipitation and had not been swept since August 2009. The initial total mass of sediment on the road was 36% of winter conditions and fine sediment was 16% of the average winter conditions. The rain event reduced total mass per unit area by 52% while the <16 µm fraction dropped 62% (Table 12). The percent reduction was nearly identical for Harold and Ace (Figure 21).

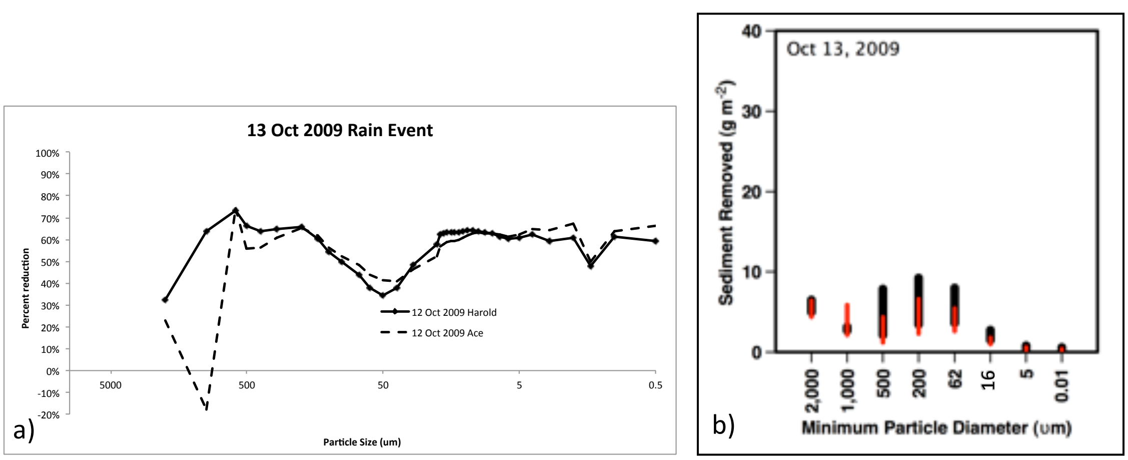

Figure 21. Reduction of road sediment on Harold and Ace by particle size for the 13 Oct 09 rain event by a) percent reduction and b) mass per unit area. The reduction was measured by the difference of the sediment mass per unit area sampled on 12 Oct and 16 Oct. Mass per unit area before and after the 13 Oct 09 rain event on Harold (thin red line) and Ace (think black line).

Table 12. Summary of sediment reduction data calculated from the difference between the "before" and "after" vacuum samples for the rain event on 13 Oct 2009.

	Pecent Reduction		Yield Reduction (g/m^2)		Mass Reduction (kg)	
	Total	<16 μm	Total	<16 μm	Total	<16 μm
Ace	49%	62%	19	0.87	84	3.9
Harold	56%	61%	18	0.65	55	2.0
Total	52%	62%	19	0.78	139	5.9

Chloride Analyses of Sediment
Sediment from three vacuum events were analyzed for exchangable chloride utilizing a 1:5 soil to water extract (Table 13). It is assumed the source of Cl is from the applied salt during the winter and the low values for the October 2009 sample support that assumption.

The meq_c/kg results indicate the sediment remaining on the roadway after sweeping either, a) has a greater cation exchange capacity consistent with a shift to smaller mean particle diameter sizes and greater specific surface areas, or b) is comprised to a greater extent of salt residues. However, decrease in meq_c *per unit area* indicates the sweeper removed an average of 72% of exchangeable Cl from the road. These data suggest street sweeping could reduce the concentration of Cl in stormwater.

Table 13. The milliequivalent charge (meq_c) per kg of sediment and per m^2 of road surface for exchangeable Cl for select vacuum samples.

			Cl	
Event	Site	Action	(meq_c/kg)	(meq_c/m^2)
06 Jan 2010	Harold	Before Sweeping	10	0.96
		After Sweeping	22	0.32
22 Mar 2010	Harold	Before Sweeping	17	4.95
		After Sweeping	47	1.07
		After Sweeping+Washoff	17	0.15
13 Oct 2009	Ace	Before Rain Event (12 Oct 2010)	5	0.20
		After Rain Event (16 Oct 2010)	2	0.043
	Harold	Before Rain Event (12 Oct 2010)	5	0.15
		After Rain Event (16 Oct 2010)	2	0.033

Drop Inlet Samples
Three drop inlets were sampled on four occasions during the two year study (Table 14). Sediment within the two DIs at the intersection with College was generally more coarse than at Harold probably because application of traction control above the Harold DI was minimal, whereas College and Ace received runoff from sections of the road that were routinely sanded. In addition, the Ace DI likely received coarse material from the College Drive chip-seal resurfacing operation in 2010. The overall average for the 12 DI samples was 7.4% fine sediment (Table 14).

The average dry mass recovered from each DI over the course of the study was 40 kg. If that mass was representative of each of the 17 DIs in the study area, then 2.7 metric tons of material would have been recovered from the 4 DI cleanings; 200 kg of that material would have been fine sediment.

Table 14. Summary data from four DI sample sets for all particle sizes (Total) and fine sediment (<16 μm).

	Total		<16 μm	
	Volume (m^3)	Mass (kg)	Fraction (%)	Mass (kg)
25 Feb 09 Harold	0.042	63	13.4%	8.44
25 Feb 09 Ace	0.016	24	14.6%	3.44
25 Feb 09 College	0.037	56	7.7%	4.30
12 Mar 09 Harold	0.057	85	8.4%	7.11
12 Mar 09 Ace	0.004	5.5	5.5%	0.30
12 Mar 09 College	0.003	4.2	5.2%	0.22
17 Jul 09 Harold	0.011	16	8.5%	1.38
17 Jul 09 Ace	0.006	8.6	9.4%	0.81
17 Jul 09 College	0.015	22	7.9%	1.70
24 Mar 10 Harold	0.021	32	12%	3.88
24 Mar 10 Ace	0.046	69	1.0%	0.69
24 Mar 10 College	0.068	101	3.6%	3.61
Average Harold	0.033	49	10.6%	5.2
Average Ace	0.018	27	7.6%	1.3
Average College	0.031	46	6.1%	2.5
Overall Average	0.027	40	7.4%	3.0

Stormwater Runoff Samples

Discharge Measurements

Monitoring discharge in the stormwater pipes was a challenge. Although Palmer-Bowlus (PB) insert flumes are intended for conveyance pipes, the measurement accuracy is diminished when the upstream slope is greater than 2%. The slope of the pipe sections immediately before the flumes used in this study was 9%. Nevertheless, the Harold flume, a traditional PB flume, represented flows accurately as evidenced by the washoff experiment, whereas the insert PB flume at Ace experienced a number of difficulties. Initial runoff events at Ace resulted in a “negative” hydrograph due to slope-induced water turbulence within the level flume that adversely impacted stage measurements. A control structure consisting of sand bags held in place by nails was installed 2 feet upstream of the flume on 30 Jan 09. A water truck test was conducted on 3 Feb 09 to confirm that stage readings were minimally affected by turbulence. In addition, the Ace flume was larger than Harold to minimize the risk of obstructing flow in the conveyance system and therefore did not measure low flows as well. Finally, the Ace site did not adequately measure the dynamic flow during the short-term (i.e., flashy) washoff experiments; however, the discharge measured during natural discharge events was not an issue as the contribution of short-term peaks to the total event volume was believed to be minor.

The resulting hydrographs (Figures 22 and 23) are dominated by chronic diurnal low-flow melt events through most of the winter and spring punctuated by occasional snow melt, rain, or rain on snow events. The rain event on 13 Oct 2010 had a discharge more than double any other runoff event.

The flow from the conveyance system draining Golfers Pass was measured using a self-contained pressure transducer in a stilling well in a drop inlet. However, repeated freezing issues appeared to corrupt the data and it could not be used.

Stormwater Events

Forty-nine stormwater runoff composites were collected from the Ace and Harold study areas throughout the study period and submitted for LPSA (Figures 22, 23, 24, and 25; Table 15). These samples represented a subset of runoff events, because, due to budget limitations, not all runoff events could be sampled and analyzed. For the entire study period, 41% of the runoff at Harold and 36% of the runoff at Ace was sampled for water quality. All but 10 of the composite samples were from natural rain or snowmelt events during the winter. The other 10 samples were from non-winter rain events (n=4) and the washoff experiments (n=6).

Sixty-two percent of the 832 kg of total suspended sediment in sampled stormwater events from Ace and Harold was sub 16 µm. This is consistent with Andral et al. (1999) that found that three-quarters of sediment in stormwater runoff was less than 50 µm. Another perspective is that over the course of the study, 250 g of sediment was removed (i.e., washed off) from every square meter of road, 155 g of which was fine sediment (calculated by dividing mass of fine sediment in stormwater by the area of the of the study area corresponding to each sample).

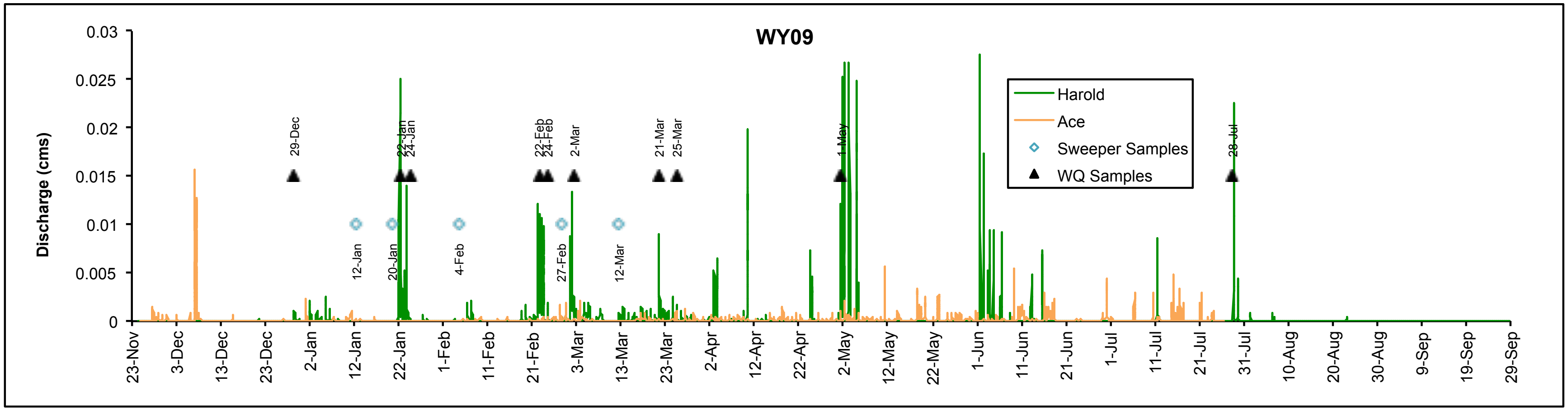

Figure 22. Discharge from Harold and Ace for the period of record in WY09.

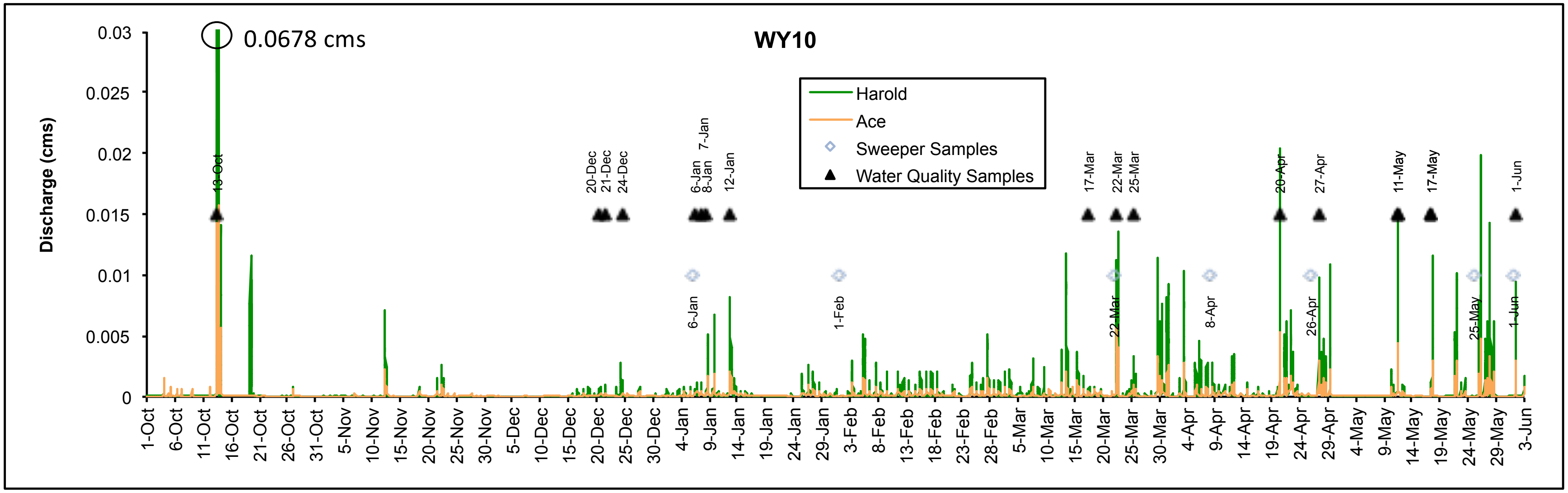

Figure 23. Discharge from Harold and Ace for the period of record in WY10.

Non-Winter Events
Four stormwater samples were collected from two non-winter rain events including three samples from a 33 mm event on 13 Oct 09 (Figures 24 and Table 15). The discharge on 13 Oct 09 was approximately 3 times larger (by volume) than the next largest storm and provided the opportunity to analyze a first and second flush at Harold. On average, the TSS of the four non-winter samples contained 43% fine particles, whereas winter events contained 71% fines. The difference is likely due to the greater fraction of fines available in the winter.

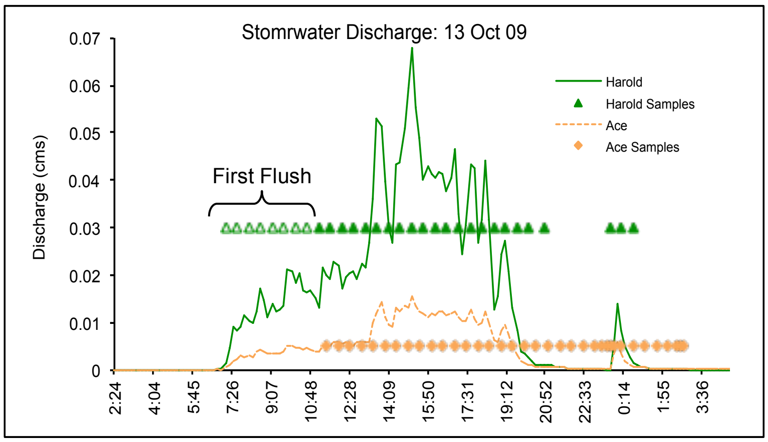

Figure 24. Hydrograph at Harold and Ace for the rain event on 13 Oct 2009.

Winter Events
Water quality data are presented in Figure 25 and Table 15. Stormwater volume and total sediment mass per unit area were well correlated (R=0.78), but volume and fine sediment mass were less correlated at 0.59. Juxtaposing sediment mass per unit area with sweeping events, there is no obvious trend of improved water quality after a sweeping event. One factor is that water quality samples were often collected days or weeks after the last sweeping event (additional detail is available in the Discussion section). Another issue is that not all runoff events were sampled. For this and many other reasons (see the Discussion section), the washoff experiments were performed to constrain the system and determine a cause and effect of sweeping and improved water quality.

Table 15. Parameters for stormwater runoff. See Figure 24 for more detail on the 13 Oct 2009 rain event.

			Yield (g/m^2)	
Event	Volume (L)	TSS (mg/l)	Total	<16 μm
29 Dec 08 Ace	7,957	4482	8.03	5.70
29 Dec 08 Harold	13,799	2978	1.74	1.50
22 Jan 09 Ace	22,588	91	0.46	0.40
22 Jan 09 Harold	28,331	563	4.46	3.71
24 Jan 09 Ace	36,755	115	0.95	0.76
24 Jan 09 Harold	467,245	280	40.7	29.5
22 Feb 09 Ace	327,935	73	5.41	4.39
22 Feb 09 Harold	434,046	173	16.4	12.5
24 Feb 09 Ace	45,686	7.1	0.07	0.06
24 Feb 09 Harold	30,990	57	0.46	0.39
2 Mar 09 Ace	70,339	53	0.85	0.64
2 Mar 09 Harold	288,118	135	11.3	7.98
21 Mar 09 Ace	6,482	650	0.95	0.65
21 Mar 09 Harold	26,295	730	4.80	2.99
25 Mar 09 Ace*		42		
25 Mar 09 Harold	9,900	59	0.05	0.05
1 May 09 Ace	84,155	92	1.74	1.50
1 May 09 Harold	304,092	231	20.1	10.8
28 Jul 09 Ace	20,929	271	1.28	1.11
13 Oct 09 Ace	314,900	70	4.93	2.13
13 Oct 09 Harold 1st Flush	203,624	149	9.75	4.57
13 Oct 09 Harold 2nd Flush	1,206,377	78	23.3	8.84
13 Oct 09 Harold Combined	1,410,001	228	33.1	13.4
20 Dec 09 Ace	7,241	330	0.54	0.47
21 Dec 09 Harold	14,439	265	1.23	0.91
24 Dec 09 Ace	3,814	979	0.84	0.71
6 Jan 10 Ace	15,781	228	0.81	0.71
6 Jan 10 Harold	12,641	305	0.08	0.12
7 Jan 10 Ace	10,936	187	0.46	0.39
7 Jan 10 Harold	21,810	208	0.80	0.70
8 Jan 10 Ace	16,381	921	3.40	2.50
8 Jan 10 Harold	34,578	384	2.23	2.61
12 Jan 10 Ace	33,046	453	2.86	2.41
12 Jan 10 Harold	78,282	1763	7.32	3.46
17 Mar 10 Ace	10,721	65	0.16	0.14
17 Mar 10 Harold	10,498	61	-0.02	-0.02
25 Mar 10 Ace	27,476	143	0.89	0.71
25 Mar 10 Harold	62,954	221	3.20	2.68
20 Apr 10 Ace	20,804	389	1.82	1.14
20 Apr 10 Harold	82,821	744	17.2	10.8
27 Apr 10 Ace**			1.53	1.02
27 Apr 10 Harold	148,796	138	4.43	2.96
11 May 10 Ace	37,721	266	2.26	1.55
11 May 10 Harold	98,444	220	3.73	3.01
17 May 10 Harold	35,037	281	3.16	2.08

*25 Mar 09 Ace; water quality was sampled and analyzed, but no volume recorded
**27 Apr 10 Ace; no volume or sample data available; sediment mass was estimated from turbidity

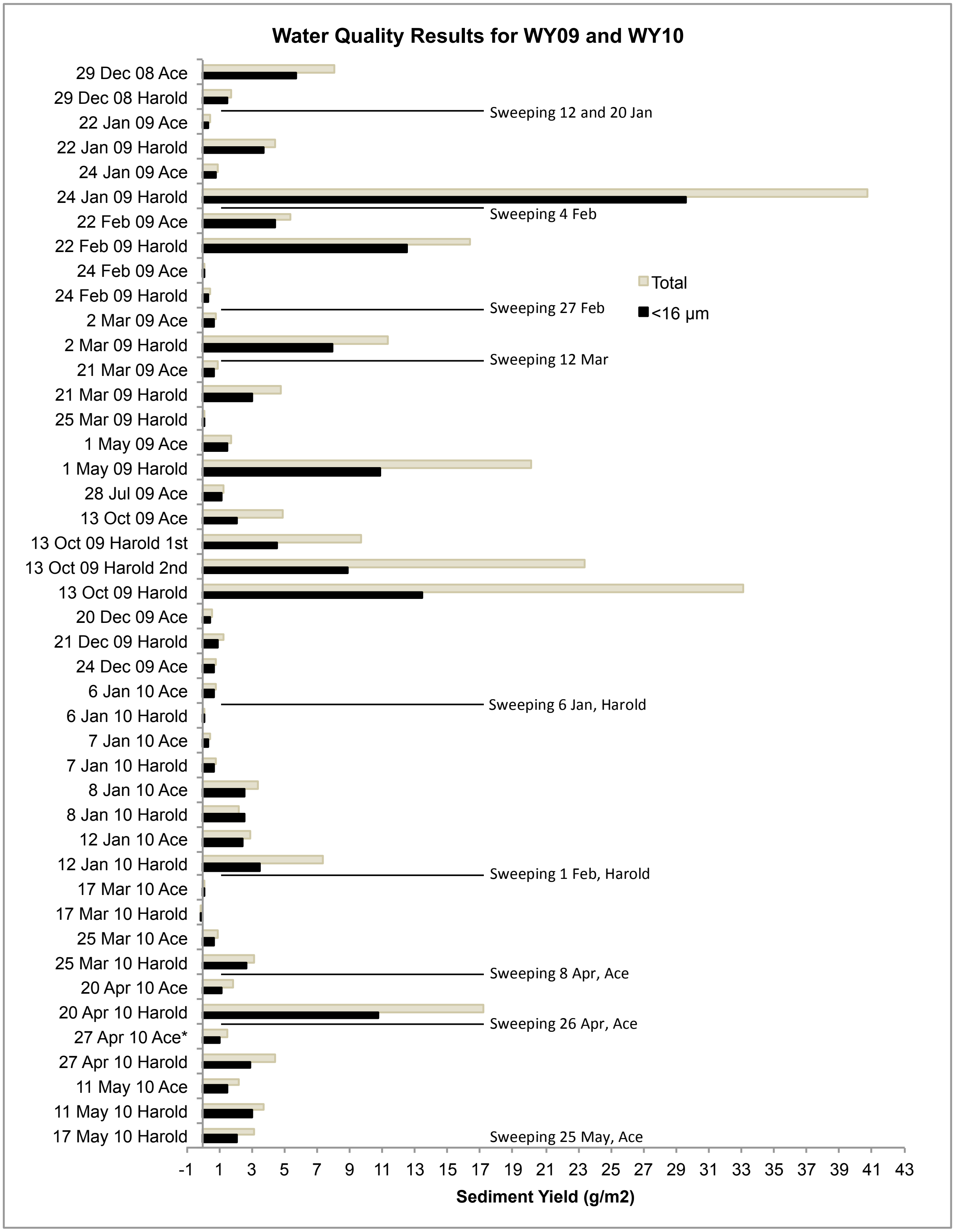

Figure 25. Total and fine (< 16 µm) sediment measured in stormwater from the Ace and Harold study areas. The dates when sweeping occurred are included for perspective. [*the 27 Apr 10 sediment mass was estimated from turbidity data.]

Water Chemistry
A subset of stormwater events were analyzed for nutrients (Harold: n=15; Ace: n=11). Overall, concentrations from the study site were similar to nearby creeks (Rosewood Creek and Incline Creek) (see Appendix B).

Turbidity
There was no consistent relationship between turbidity and discharge, but the highest flows generated relatively low turbidity and the highest turbidity was at very low flow (Figure 26). Relating turbidity to sediment concentration would be beneficial, but that analysis was outside the scope of this effort.

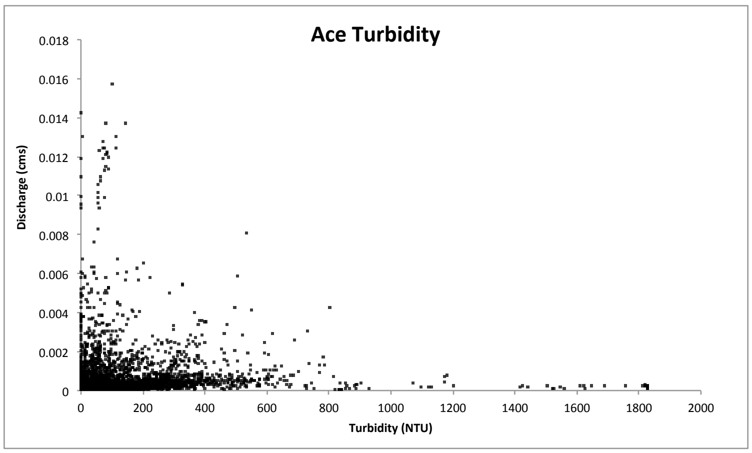

Figure 26. Discharge/Turbidity plot for the Ace monitoring station for the period of record.

Washoff Experiments

To constrain the system, a known volume of water was applied to the study areas over a short period and intensively sampled to establish a relationship between street sweeping and water quality. Tables 3 and 4 provide a summary of actions in each study area during the washoff events on 22 Mar and 1 Jun 2010.

Washoff Hydrograph

The target application rate from the water truck to each study area was 0.5 inches over 2 hours, or 10,000 gallons (5 truck loads) on Harold and 12,000 gallons (6 truck loads) on Ace. However, due to the uncertainty of the water truck fill and discharge rates, and time considerations, the 0.25 in/hr application rate was not achieved (see Table 16 and the Methods section for more information).

The hydrographs resulting from the application of washoff water are shown in Figures 27 and 28. The flashy flow was a challenge to completely capture at the monitoring sites because of the 2-minute stage interval, and is evident as not all of the peak discharges are evident in Figures 27 and 28, although the slower release on 1 Jun resulted in more detail in the hydrograph. However, for both washoff events, the flow measured at Ace was one-third the known volume of water applied (for reasons explained in the water quality results). As a result, for the washoff experiments, the volume measured at Harold was used to calculate sediment mass from the Ace study area (using the TSS concentrations collected at Ace).

Table 16. Volume and effective rate of application of water to the study area for the washoff experiments.

	Volume (gallons)		Rate (in/hr) [(mm/hr)]	
	Ace	Harold	Ace	Harold
Target	15,000	10,000	0.25 [6.4]	0.25 [6.4]
22-Mar	12,000	10,000	0.3 [7.6]	0.45 [11.4]
1-Jun	12,000	10,000	0.22 [5.6]	0.3 [7.6]

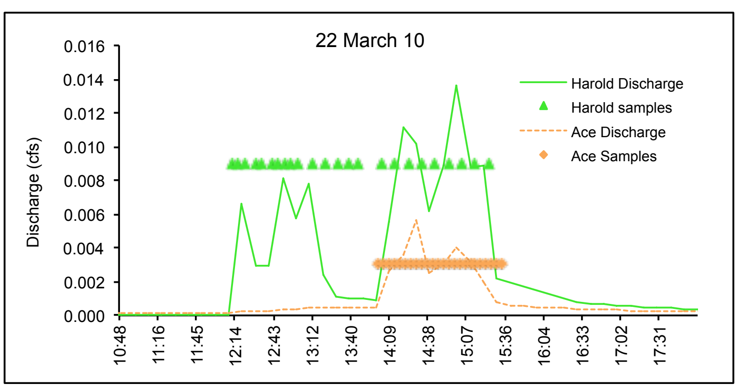

Figure 27. Flow resulting from the 22 Mar washoff experiment at Harold and Ace.

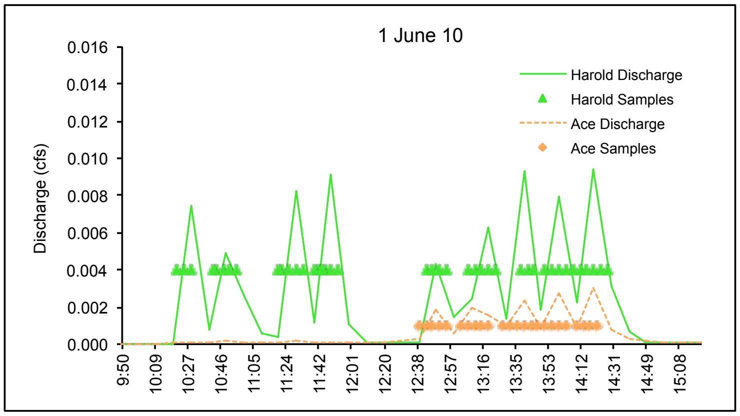

Figure 28. Flow resulting from the 1 June washoff experiment at Harold and Ace.

Washoff Sweeper and Vacuum Results

22 March Washoff

The Harold study area had been swept twice earlier in the winter, but a combination of extreme weather and sweeper maintenance issues prevented sweeping since 1 Feb 2010 (Figure 16). As a result, the mass per unit area recovered by the sweeper was easily the largest for the entire study (Table 8). In fact, the sediment recovered from Harold on 22 March filled the sweeper twice and required a third pass before the Harold study area was considered completely swept. Unfortunately, the corresponding vacuum samples indicate the sweeper only collected 20% of what the sweeper actually collected (Figure 29). It is likely, based on observations, that the vacuum was not capable of collecting the density of sediment material found at Harold (and Ace) on 22 March. Nevertheless, the vacuum samples show a reduction of 265 g/m^2 (92%) of total sediment, and 12 g/m^2 (66%) of fine sediment (Table 17) from Harold. The subsequent washoff event removed an additional 62% and 83% of the total and fine sediment, respectively. Together the sweep+washoff combination removed 279 g/m^2 (97%) of total sediment and 16 g/m^2 (94%) of fine sediment (Table 17).

The Ace study area had not been swept since November 2009, and like Harold, the vacuum data indicated the sweeper only collected 20% of what the sweeper actually collected. The washoff at Ace for the 22 Mar experiment removed 80 g/m^2 (43%) of the total sediment 5.6 g/m^2 (50%) of fine sediment. The subsequent sweeping removed an additional 76% total and 50% fine sediment (Table 17). Together the washoff+sweep combination removed 161 g/m^2 (87%) of total sediment 8.4 g/m^2 (74%) of fine sediment (Table 17). The final fine sediment mass per unit area on Ace (2.9 g/m^2) was slightly better than the minimum of 3.3 g/m^2 found for non-washoff samples.

1 June Washoff

After the 22 March washoff experiment, Ace was swept 4 times including the week prior to the 1 June washoff experiment, whereas Harold had not (see Table 4 for the sequence of actions for the 1 June experiment). Although some snow had fallen since 22 March, Washoe County personnel did not believe any traction control material had been applied since 7 March (but the computer files confirming this were lost). The combination of recent sweeping and no application of traction control material may explain the very low initial mass per unit area found on Ace and Harold (Table 17).

Sediment reduction on Harold from the washoff was 53 g/m^2 (71%) of total sediment and 4.7 g/m^2 (81%) for fine sediment, respectively, resulting in a fine sediment mass per unit area as low as the 22 Mar sweep+washoff combination on Harold (Table 17).

The initial sediment mass per unit area sampled on Ace for 1 June revealed a decrease of 1 g/m^2 (5.3%) from the previous week (Table 9) for total sediment and 1.2 g/m^2 (36%) for fine sediment. The reduction of the fine sediment could be due to entrainment into the atmosphere for the fine by vehicles or track-out of coarse sediment. After sweeping, fine sediment mass per unit area increased slightly (Table 17). The subsequent washoff, however, was very effective at reducing fine sediment down to 0.6 g/m^2 (71%).

Table 17. Sediment removal statistics for the two washoff experiments based on analyses of vacuum samples.

			Yield (g/m^2)		Pecent Reduction	
	Study Area	State	Total	<16 µm	Total	<16 µm
22-Mar	Harold	Initial conditions	288	17		
		After sweeping	23	5.8	92%	66%
		After washoff	8.7	0.96	62%	83%
	Ace	Initial conditions	186	11		
		After washoff	106	5.7	43%	50%
		After sweeping	25	2.9	76%	49%
1-Jun	Harold	Initial conditions	75	5.8		
		After washoff	22	1.1	71%	81%
	Ace	Initial conditions	18	2.1		
		After sweeping	14	2.2	22%	-5%
		After washoff	7.0	0.63	50%	71%

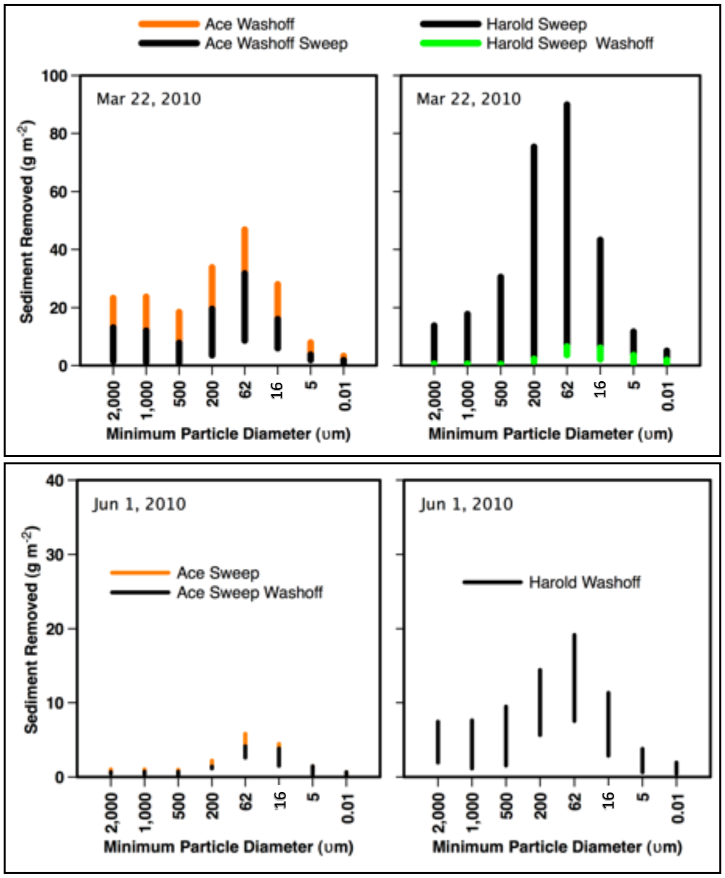

Figure 29. Sediment mass per unit area removed from the road during the 22 Mar 09 washoff experiment. Note that the vertical scale is different between the 22 Mar event and the 1 Jun event.

Washoff Water Quality

The primary purpose of the washoff experiments was to determine if stormwater quality from the swept study area was better than the unswept study area. Table 18 shows that the water quality of the swept study area contained approximately 50% less fine sediment than the unswept (46% less for the 22 March washoff, and 61% less for the 1 June washoff).

Table 18. Mass and mass per unit area of fine sediment in washoff water for Ace and Harold.

		mass (kg)		yield (g/m^2)	
		Total	<16 µm	Total	<16 µm
22-Mar	Harold	50	24	16	7.5
	Ace	120	61	39	14
1-Jun	Harold	45	18	10	5.9
	Ace	18	10	4.0	2.3

Turbidity provides additional detail of the behavior of sediment during the washoff. Figure 30 indicates turbidity levels tend to fall off more quickly from swept study areas compared to unswept study areas.

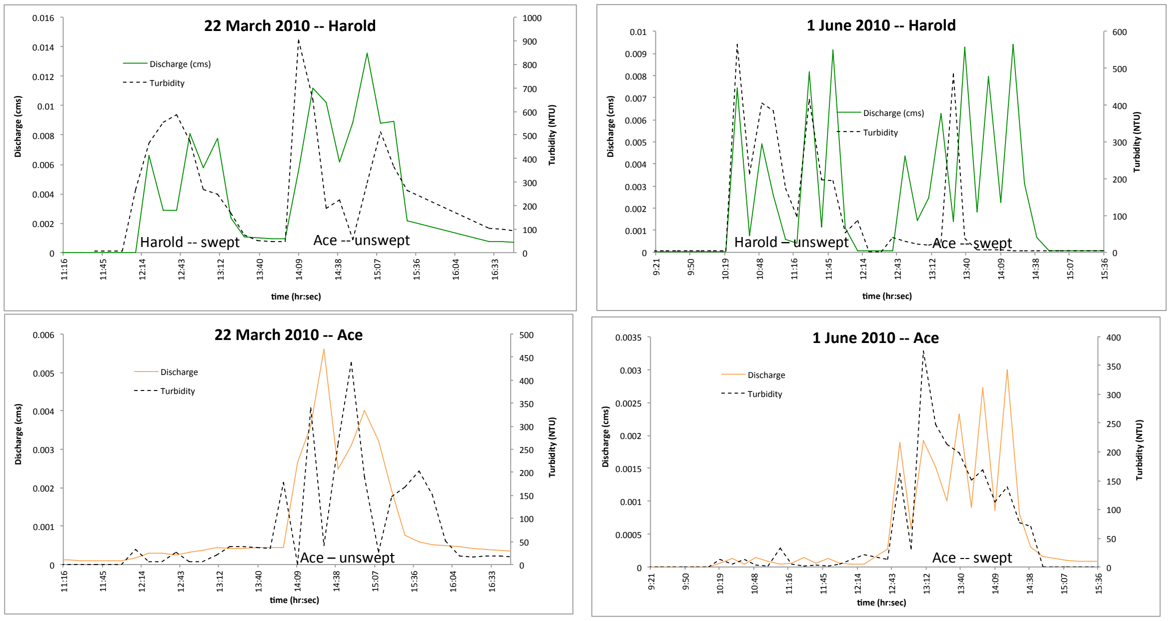

Figure 30. Discharge with turbidity for the washoff events at Harold and Ace using 10 minutes data. Note that each panel has different vertical scales.

DISCUSSION

As a pilot study, it was important to collect a broad spectrum of data using cost effective methods and to determine which was most effective to collect samples in the Tahoe environment. Measuring the mass of fine sediment in an environment that was as close as possible to actual conditions was important to lend veracity to the results. However, the effort required to adequately constrain the system for accurate, repeatable stormwater measurements was under estimated and resulted in creation of the washoff experiments.

In retrospect, it should have been obvious that a system dominated by snow would be challenging to analyze. Precipitation as snow may not runoff for days or weeks, sometimes in a rate so low that it was difficult to sample. Other issues also complicate sampling and analyses. First, the road sediment mass per unit area often increased during a snowstorm due to the application of traction control material. When the snow melts, the stormwater TSS concentration may not represent the mass of sediment on the road the when it was last sampled by the vacuum (days or weeks prior). Second, snowplows remove (i.e., cast-off) snow and sediment from the road. The cast-off snow is unquantified precipitation removed from the study area. Likewise, existing road sediment and new traction control material mixes with snow and may be cast-off by the snowplow. Snow piles off the road contain sediment that was permanently removed from the study area. Third, if precipitation from a winter storm falls as rain, existing snow and ice on the road will melt and add water volume to the runoff. Simultaneously, sediment would be released from the melting snow and ice, and increase the sediment mass in the stormwater runoff. Fifth, the stormwater input from College Dr. and Golfers Pass conveyances were not quantified, the later of which could have been substantial. For all these reasons, a straight cause and effect relationship between sweeping and water quality was not possible for natural winter runoff events. To help constrain the system, the washoff experiments were created. This inexpensive, repeatable experiment indicated street sweeping improved stormwater quality by 50% and should be considered for use in future studies.

Other successes that warrant consideration in future studies include:

Vacuum sampling: the method of using a vacuum cleaner to sample road sediment was a success. The vacuum was portable, easy to set up, posed minimal disruption to traffic, and was repeatable. Two limitation were noted. First, samples could not be collected when the roadway was wet, but that is minor issue because street sweepers require dry roads to operate efficiently. Second, very large sediment mass per unit area experienced on 22 March 2010 appeared to overwhelm the vacuum resulting in an under sampling of the road sediment.

Vacuum bags: The procedure of removing material captured in the fabric of the vacuum bag by washing was also a success. Other studies have either ignored this issue (e.g., Selbig and Bannerman 2007) or used a very labor intensive and tedious method (e.g., Rochfort et al. 2007).

Sweeper performance: The procedure to characterize the performance of the sweeper by vacuuming the road immediately before and after street sweeping was successful in large part because of the outstanding support from Washoe County personnel.

Mass Balance

The sediment mass per unit area collected by the sweeper and that predicted by the vacuum samples (i.e., the mass per unit area of the "before" samples minus the "after" samples) ideally should be the same. For the entire study period, the total sediment mass estimated by the vacuum samples was 50% of that collected by the sweeper (Table 19). The two quantities were in better agreement for WY09 when the vacuum collected 87% of the mass collected by the sweeper. Therefore the primary discrepancy between the vacuum and sweeper data is in WY10.

Table 19. A summary of total and fine sediment mass and yield for quantified sources and sinks in WY09 and WY10. The yield is the mass of each of the four sediment categories normalized to the total area *swept* for that year (mass per unit area (g/m^2)). "Abrasives" is only the sand portion of the traction control material. "Sweeper" is the sediment collected by all sweeper events (except 4 Feb 2009 sample and the second sweeping on 12 Jan 2009 because neither had a companion vacuum sample). "Vacuum" is the sediment collected by the vacuum extrapolated to the entire study area. "Stormwater" is the total mass of sampled events from Harold and Ace. "Overall" is the sum of the mass divided by the area swept for the entire study.

	Mass (kg)						Yield (g/m^2)					
	WY09		WY10		Overall		WY09		WY10		Overall	
	Total	<16 μm	Total	<16 μm	Total	<16 μm	Total	<16 μm	Total	<16 μm	Total	<16 μm
Sweeper	1948	104	5650	333	7598	437	64	3.4	179	11	123	7.1
Vacuum	1692	117	2090	75	3781	192	56	3.9	66	2.4	61	3.1
Abrasives	250	3.0	215	2.6	465	5.6	8.3	0.099	6.8	0.082	7.5	0.091
Stormwater	394	280	537	256	931	536	13	9.2	14	8.1	13	8.7

Figure 31 graphically compares the two data sets for total and fine sediment for the vacuum and sweeper data. A good correlation was found between the vacuum and sweeper data for total sediment mass over the entire study period (Pearson's correlation coefficient of 0.73 for Ace and 0.89 for Harold, n=16), but fine sediment was only moderately correlated (Pearson's correlation coefficient of 0.49 for Ace and 0.54 for Harold, n=16). The issue for the fine sediment fraction was the sweeper consistently collected more fines per unit area in WY10 than the vacuum (Figure 31) resulting in nearly 5 times more fines than the vacuum samples (Table 19). This suggests the method of incorporating the fine sediment shaken from the sweeper's filter into the bulk material used in WY10 may have been inadequate.

Table 19 also compares the mass and sediment yield for sweeper, vacuum, abrasives, and stormwater. It shows the sweeper collected 16 times the mass applied as abrasive material (only the sand fraction of the traction control material). This is somewhat in line with Washoe County's internal data for previous years that estimates 5.4 times more total sediment was collected by the sweeper than was applied as traction control. It appears that additional sediment was transported into, or generated within, the study areas.

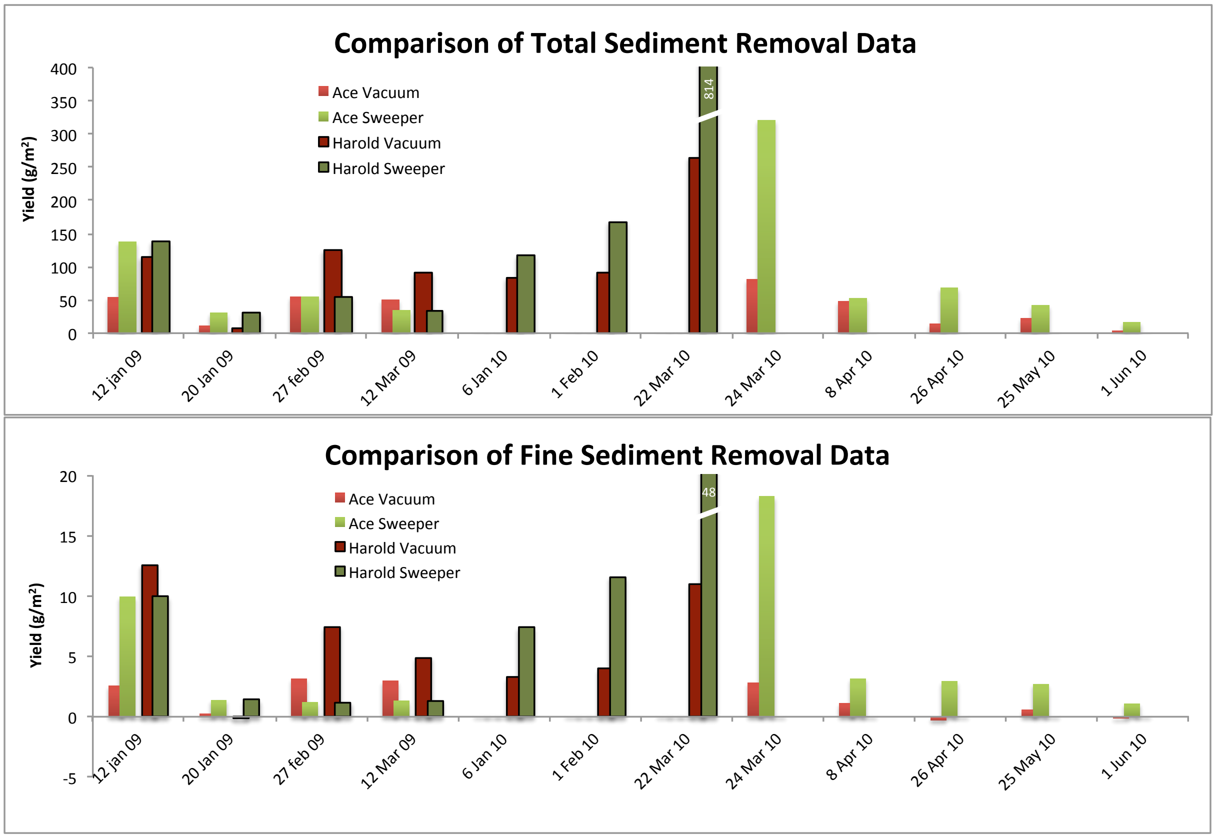

Figure 31. Comparison of total sediment (upper graph) and fine sediment (lower graph) mass per unit area for Ace and Harold for each sweeper event.

For fine sediment, 78 times more fine sediment mass was collected by the sweeper than was applied. Again, this suggests a source of fine sediment was transported into, or generated within the study areas. The additional sediment could have come from a number of sources, including:

1. Track-in. Although not measured, it was assumed that sediment tracked in by vehicles would be balanced by track-out.
2. Pine needles, pine cones, and trash. The sweeper collected a sizable, but unquantified amount of organic (i.e., non-geologic) material dominated by pine needles and pine cones that fell from the adjacent trees on to the road. The bulk density of the sweeper material was measured as 1.36 g/cm^3 (n=2) and is approximately half the density of granite and should have compensated for the additional volume from organic sources.
3. Cut slopes. Sloughing of material from cut slopes behind the curb on Village Blvd. was possible, but these areas were few and usually covered with snow throughout the winter. In addition, no material from these sources was observed in the study area.
4. Atmospheric deposition. Some small portion of sediment could have blown in from other sources, but, during most of the winter the ground was covered with snow and prevented blowing sediment. More likely is that fine dry sediment was entrained into the atmosphere by cars and removed from the roadway to be deposited on snow piles adjacent to the road.

5. Breakdown of the road surface. The road surface could deteriorate in two ways.
    a. Chucks of asphalt were frequently observed to break off at the junction of the concrete curb and the road surface. The mechanism for this degradation could be freeze/thaw or contact with the blade of a snowplow. Although unquantified, these chunks could be a good source of coarse material mass because the chunks generally remained in the gutter.
    b. Abrasion of the road surface could be a major source of mostly fine sediment. Abrasion results from the interaction of vehicle tires and the winter abrasive material used for traction control, studded snow tires and chains, and the action of the snowplow on the road. Although this study could not prove road wear to be the source of additional sediment, the degradation of the road is clearly evident in the wheel ruts, some of which were 19 mm (0.75 inches) deep relative to the adjacent asphalt. Assuming a wheel rut was 45 cm wide (18 inches), then 1 mm of road wear on all for wheel ruts would result in 677 kg of sediment (assume asphalt density of 2 g/cm^3), most of which would likely be fine sediment.

If confirmed as a source of sediment, road wear could be mitigated by banning the use of chains and studs, paving the road with harder aggregate, and possibly using a softer winter abrasive. El Dorado County, for example, is using septic-grade decomposed granite, a plentiful native material, as traction control. Another solution is to sweep the roads as soon as possible after abrasives are applied—a practice that Washoe County has already adopted.

The Problem With Curbs

The intent of installing curb and gutter is to prevent erosion of roadside soils during high flow events by conveying surface flows to a stormwater treatment system. The result is flashy, high volume flows at a conveyance discharge point that must be treated before discharge to a natural drainage. Designing adequate treatment systems to remove fine sediment presents a distinct challenge to stormwater engineers.

Another less obvious consequence of curbs is that less snow is removed from the road. During snow removal operations, road maintenance crews avoid damaging curbs by maintaining a buffer between the plow blade and the curb. On Village Blvd. this practice frequently resulted in snow 2 to 3 feet deep and 1 to 2 feet into the road, despite attempts by the road maintenance personnel to keep the gutter clear for this experiment (Figure 32). The amount of snow and ice in the road is documented by this study by the inability to vacuum to the curb on many occasions (Table 9). As the snow in the road melts, water flows where the majority of sediment is located—along the curb—and moves that material to the stormwater outfall where it becomes a treatment issue. The melting snow also prevents the street sweeper from accessing the gutter where the majority of sediment is located. The remaining sediment in the gutter is available to be mobilized during larger runoff events (e.g., rain on snow). Without a curb, the snow is generally cast completely off the road where melting snow can infiltrate into the soil. Curb and gutter likely have a place in the Tahoe Basin, but the disadvantages should be more thoroughly considered before installation.

Figure 32. The curb area of Village Blvd. in the winter. The entire concrete gutter is covered with about 3 vertical feet of snow and ice containing road sediment.

Where Do Drop Inlets Fit?

This project demonstrated that 7.4% of the volume of sediment removed from drop inlets was fine material (nearly the same ratio as the sediment found on the road). The expectation was that a negligible portion of fines would be captured because fine sediment in the sump area of the drop inlet would be well mixed and never settle. However, it is possible that the very low flow associated with diurnal snowmelt minimized turbulence in the sump. In addition, the physical separation of the in-flow and out-flow of the drop inlet was sufficiently large to allow fine sediment to settle.

Cleaning all 17 drop inlets 4 times during the study could have recovered 2,700 kg of sediment. This mass is only 30% of that collected by the street sweeper. However, the total mass of sediment in *sampled* stormwater events was 931 kg (Table 19). These data suggest drop inlets substantially reduce sediment in stormwater runoff. However, for the pollutant of concern, fine sediment, stormwater transported 536 kg whereas drop inlets sequestered only 200 kg. In addition, little is known about the potential for large flows to resuspend sediment from drop inlets, potentially negating their benefit. Additional studies should be conducted to more fully appreciate the role DIs and sediment cans have in the sequestration of fines in the Tahoe environment.

One addition consideration; if the number of drop inlets per unit area in Harold were in Ace, then Ace would have had 8.5 drop inlets. But Ace had 11 drop inlets. The additional 2.5 drop inlets could have reduced the TSS concentration in stormwater from Ace.

Street Sweeping in Tahoe

Street sweeping is an important component in the effort to reduce the source of fine sediment from road surfaces. During the two-year study, 7.6 two-lane km were swept collecting 9,250 kg of material or 1.2 kg/m (4,299 lbs/mile); of that, 70 g/m (246 lbs/mile) was fine sediment. Selbig and Bannerman (2007) found up to 776 lbs/mile on residential streets in Madison, WI.

Although waterless street sweepers can be used in the winter, manufacturers recommend street sweepers be used when the road is completely dry. Unfortunately, snow, ice and, and melting snow prevented access to the gutter areas of the road for much of the winter (see the discussion on “curbs” above). On average, 11% of Ace and 20% of Harold could not be vacuumed (or swept) each time the road was swept (Table 9).

The initial mass per unit area (total and fine) on Harold was, on average, greater than Ace, but after sweeping, the remaining mass per unit area (total and fine) on Harold was less than Ace (Table 9). There are probably two reasons for this. First, Ace had only 40% of the traffic found on Harold (Table 5) (remember there is a strong relationship between traffic volume and sediment load (Pitt et al. 2004)). Second, the antecedent moisture level was likely lower on Harold than Ace because of Harold’s southern aspect. So more traffic may explain the greater initial mass, and the lower moisture content of the sediment may explain the smaller remaining mass.

Ideally, Tahoe roads would be swept daily during the winter, but sweeping as soon as a road is dry (or mostly dry) is more practical. This practice collects road sediment before it can be ground into fine sediment (or abrade the road surface). Sweeping as soon as possible, reduces fine sediment entrainment into the air (reducing air pollution), improves vehicle safety, and improves aesthetics. However, as the sediment accumulation during the week between 12 Jan 09 and 20 Jan 09 illustrate, sediment will accumulate on a road during completely dry periods. Had the street not been swept on 20 Jan, then an additional 1.3 g/m^2 of fines would have been available to the stormwater runoff on 22 Jan 09. Therefore, it may be the most cost efficient, from a water quality perspective, to sweep all roads immediately before precipitation events.

Another strategy for determining when to sweep is to determine the minimum practical mass per unit area of fine sediment on the road. The data from this study suggests that 3.3 g/m^2 of fine sediment is about as good as this sweeper can do. On the two occasions when the initial mass per unit area was below 3.3 g/m^2 (20 Jan 09, Harold and 1 June 10, Ace (Table 9)), sweeping increased the fine sediment sampled by the vacuum. The street sweeper is unlikely to have actually increased the mass of fines on the road…after all, some fine sediment was collected by the sweeper. Instead, the sweeper likely redistributed fine sediment on the road and removed larger sediment, making more fine sediment available to the vacuum. But this is a relatively minor point. More importantly, if 3.3 g/m^2 can be equated to a road “condition” as defined by the Road RAM, then road maintenance personnel would have a better metric to determine when to sweep.

CONCLUSIONS

This report contributes to understanding the characteristics of fine sediment load on Village Blvd. in Incline Village, NV and the capabilities and limitations of street sweeping using the Tennant Sentinel street sweeper. Although the report has implications for the rest of the Tahoe Basin, the use of different traction control material, different street sweepers, and different operational procedures may not produce the same results. The operational profile guiding this study was to have the road maintenance crew of Washoe County follow existing operational procedures as much as possible which conveniently coincided with the study objective to sweep as frequently as possible. Other jurisdictions may not sweep as frequently.

The Washoe County street sweeper collected 9,250 kg over the course of the study, 77% of the total and 47% of the fine sediment on Village Blvd. By constraining the stormwater inputs during the “washoff” experiments, it was shown that street sweeping reduced fine sediment mass per unit area in stormwater approximately 50%.

The minimum practical fine sediment mass per unit area that the street sweeper could achieve was 3.3 g/m^2. Equating 3.3 g/m^2 with road condition may help maintenance crews decide when sweeping a street may be impractical.

Unfortunately, stormwater is much better at removing fines from the roadway than the sweeper resulting in fine sediment mass per unit area as low as 0.4 g/m^2 (Table 9). So although street sweeping improves water quality, post runoff treatment strategies will always be needed to remove fines from stormwater. Another need for stormwater treatment systems arise from the need to sweep roads when they are dry…a condition that is infrequent in Tahoe winters because of chronic snow, ice, and melt water on the roads.

Drop inlets may have collected a substantial portion of total sediment when compared to the sediment mass in stormwater. As a minimum, drop inlets in this system likely decrease maintenance issues downstream (for example, at the hydro-dynamic separator and settling basin), but drop inlets may play a more significant role in capturing fine sediment than originally thought and warrants further investigation.

The mass per unit area of traction control abrasives represented 6.1% of the sediment collected by the sweeper (Table 19). This indicates that another source of sediment dominates the material collected by the sweeper and the authors suggest road wear as a likely candidate.

This study validated the use of the residential vacuum cleaner as a fast, repeatable method to sample road sediment. The use of cloth vacuum bags and innovative shaking and wash procedures also proved valuable.

ACKNOWLEDGEMENTS

This study is the result of the financial support of the USDA Forest Service, Lake Tahoe Basin Management Unit, through an Erosion Control grant; and Nevada Division of State Lands, Lake Tahoe License Plant grant. Dick Minto and the crew at the Washoe County, Incline Village, roads department were no less instrumental in the success of this study…they were consistently helpful and responsive in their support. In addition, many scientists, operators, and regulators provided feedback on many occasions that helped focus this effort; in particular, Nicole Beck (2NDNature) provided many constructive comments.

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APPENDIX A: ANALYTIC METHODS

Table A-1. Analytic laboratory methods.

Analyte	Method	Description	Reporting Limit	Laboratory
Ortho-Phosphate	EPA 365.1	Phosphomolybdate	1 ug/l	DRI Water
Total Phosphorus,	USGS I-4600-85	Persulfate Digestion,	1 ug/l	DRI Water
Dissolved Phosphorus	EPA 365.1	Phosphomolybdate		
Nitrite	EPA 353.2	Colorimeric, Automated	1 ug/l	DRI Water
Nitrate	EPA 353.2	Colorimetric, Automated, Cadmium Reduction	1 ug/l	DRI Water
Ammonia	EPA 350.1	Colorimetric, Automated Phenate	1ug/l	DRI Water
Total Kjeldahl Nitrogen, Dissolved Kjeldahl	EPA 351.2	Block Digestion, Phenate	50 ug/l	DRI Water
Total Suspended	EPA 160.2	Gravimetric	0.1 mg/l	DRI Water
Solids				
pH	SM4500H+ B	Electrometric	NA	DRI Water
Total suspended soilds	ASTM, 2007a. D 3977-97	Micromeretics Saturn DigiSizer 5200®		DRI Soil
Laser Particle-size	ASTM, 2007b. C1070 – 01			DRI Soil

APPENDIX B: RAW DATA TABLES

Table B-1. Particle size and mass data for all sediment samples collected with the vacuum. Samples collected before the road was swept are labeled “before” and samples collected from the swept road are called “after.” The samples collected after the washoff events on 22 and 24 Mar and 1 and 2 Jun are labeled “Afterrain.”

			Percent Distribution by Particle Size (µm)						
Site	Date	Dry Mass (kg)	Mean	>2000	2000 - 500	500 - 125	125 - 62.5	62.5 - 17	≤16
Ace Before	12-Jan-09	1.11	169.1	6.3%	31.7%	25.2%	11.0%	14.7%	11.1%
Ace After	12-Jan-09	0.32	221.0	2.8%	12.9%	19.4%	13.9%	27.4%	23.6%
Harold Before	12-Jan-09	1.05	196.0	5.7%	26.2%	32.3%	10.6%	14.2%	11.3%
Harold After	12-Jan-09	0.17	189.9	2.0%	8.2%	24.9%	15.8%	26.9%	21.9%
Ace Before	20-Jan-09	0.32	214.0	3.3%	18.1%	32.9%	16.6%	18.9%	10.0%
Ace After	20-Jan-09	0.21	227.3	3.1%	13.6%	28.1%	16.3%	23.3%	15.4%
Harold Before	20-Jan-09	0.18	221.8	3.4%	15.3%	33.2%	15.9%	19.5%	13.0%
Harold After	20-Jan-09	0.12	227.2	2.2%	11.0%	26.7%	16.3%	24.5%	19.4%
Ace Before	27-Feb-09	0.82	191.5	6.7%	24.1%	28.5%	14.8%	17.3%	8.6%
Ace After	27-Feb-09	0.24	233.7	3.7%	13.8%	21.3%	15.9%	28.2%	16.9%
Harold Before	27-Feb-09	1.34	240.9	6.3%	25.6%	32.6%	12.8%	14.9%	8.0%
Harold After	27-Feb-09	0.25	247.7	2.0%	9.9%	22.8%	16.3%	28.6%	19.9%
Ace Before	12-Mar-09	0.88	206.3	13.0%	29.4%	21.2%	8.6%	18.2%	10.1%
Ace After	12-Mar-09	0.29	191.7	3.4%	10.7%	21.2%	15.4%	28.0%	21.5%
Harold Before	12-Mar-09	0.88	238.1	12.6%	30.5%	27.1%	11.4%	12.5%	6.8%
Harold After	12-Mar-09	0.13	174.8	3.8%	10.4%	23.3%	16.6%	28.0%	18.2%
Ace Before	12-Oct-09	0.57	145.4	17.0%	27.7%	34.9%	10.3%	7.0%	3.2%
Ace Afterrain	16-Oct-09	0.26	141.8	26.1%	27.7%	26.7%	10.4%	7.4%	1.6%
Harold Before	12-Oct-09	0.31	156.9	20.6%	32.8%	30.3%	8.4%	5.4%	2.5%
Harold Afterrain	16-Oct-09	0.13	142.7	31.8%	24.2%	25.4%	10.5%	6.6%	1.4%
Harold Before	6-Jan-10	0.40	88.5	8.1%	29.5%	26.4%	13.7%	16.1%	6.2%
Harold After	6-Jan-10	0.05	50.3	1.2%	4.6%	20.3%	24.0%	35.1%	14.8%
Ace Before	1-Feb-10	0.94	58.0	19.7%	19.8%	16.7%	14.4%	21.4%	8.1%
Harold Before	1-Feb-10	0.94	73.4	3.9%	15.2%	28.5%	19.5%	26.3%	6.6%
Harold After	1-Feb-10	0.15	41.2	1.7%	3.8%	14.3%	21.0%	41.7%	17.5%
Ace Before	22-Mar-10	2.58	94.8	12.7%	23.0%	29.2%	14.8%	14.9%	5.3%
Ace Afterrain	24-Mar-10	1.57	93.9	12.5%	18.9%	31.6%	17.1%	15.0%	4.9%
Ace Afterrain_sweep	24-Mar-10	0.32	68.2	6.2%	9.9%	28.2%	22.1%	23.9%	9.7%
Harold Before	22-Mar-10	2.62	114.3	4.9%	17.0%	41.1%	17.2%	14.9%	5.0%
Harold After	22-Mar-10	0.21	41.2	3.4%	5.9%	21.2%	19.6%	27.0%	22.9%
Harold Afterrain	22-Mar-10	0.05	83.0	4.4%	2.5%	34.3%	29.0%	24.5%	5.4%
Ace Before	8-Apr-10	0.97	76.8	10.8%	20.7%	25.4%	17.8%	19.3%	6.0%
Ace After	8-Apr-10	0.26	45.0	3.3%	6.9%	17.5%	21.2%	34.4%	16.6%
Harold_Before	8-Apr-10	0.78	91.0	10.0%	21.5%	30.5%	15.2%	16.9%	6.0%
Ace Before	26-Apr-10	0.70	74.3	6.2%	12.8%	30.0%	20.5%	22.2%	8.3%
Ace After	26-Apr-10	0.45	49.2	8.0%	13.7%	18.4%	18.9%	27.4%	13.7%
Harold Before	26-Apr-10	1.39	125.0	7.4%	25.3%	36.2%	13.8%	12.6%	4.7%
Ace Before	25-May-10	0.60	74.8	9.0%	17.2%	27.5%	19.1%	19.4%	7.9%
Ace After	25-May-10	0.24	46.8	5.7%	9.3%	17.8%	21.2%	30.6%	15.4%
Harold Before	25-May-10	1.27	108.8	7.3%	19.4%	38.5%	16.8%	12.9%	5.1%
Ace Before	1-Jun-10	0.23	64.5	6.0%	11.9%	26.2%	21.0%	25.3%	9.7%
Ace After	1-Jun-10	0.20	53.7	5.1%	11.2%	21.8%	20.5%	27.9%	13.4%
Ace Afterrain	2-Jun-10	0.10	83.7	7.0%	9.5%	33.2%	23.3%	21.1%	5.8%
Harold Before	1-Jun-10	0.72	94.3	10.1%	23.2%	30.7%	14.8%	14.8%	6.3%
Harold Afterrain	2-Jun-10	0.21	120.6	9.2%	12.7%	43.2%	19.0%	12.7%	3.3%
Fourteenth	22-Mar-10	0.35	106.0	4.9%	21.4%	35.4%	18.0%	15.9%	4.4%
Fourteenth	25-May-10	0.09	98.0	5.4%	21.3%	32.6%	19.7%	16.8%	4.1%
Fourteenth	1-Jun-10	0.11	40.8	2.5%	7.7%	16.6%	19.4%	34.7%	19.2%

Table B-2. Particle size and mass data for all sediment samples collected with the sweeper. "Both" indicates both Ace and Harold were swept.

			Particle Size (μm)						
Site	Date	Dry Mass (kg)	Mean	>2000	2000 - 500	500 - 125	125 - 62.5	62.5 - 17	≤16
Sweeper-both	12-Jan-09	2867	152.7	10.6%	28.0%	29.1%	11.8%	12.6%	8.7%
Sweeper-both	12-Jan-09	573	93.1	7.1%	16.0%	30.2%	21.0%	13.0%	13.8%
Sweeper-both	20-Jan-09	573	204.2	7.6%	25.0%	43.7%	11.5%	7.5%	5.0%
Sweeper-both	4-Feb-09	919	178.1	0.0%	0.0%	1.2%	11.3%	44.6%	42.9%
Sweeper-both	4-Feb-09	3807	178.1	16.9%	38.2%	21.9%	8.5%	9.0%	6.5%
Sweeper-both	27-Feb-09	1078	283.0	6.8%	32.3%	37.4%	14.4%	6.6%	3.4%
Sweeper-both	12-Mar-09	688	286.5	10.9%	36.2%	25.8%	8.0%	14.7%	5.3%
Sweeper-Harold	6-Jan-10	1044	90.9	12.0%	28.0%	27.0%	12.6%	13.4%	7.0%
Sweeper-Harold	1-Feb-10	1502	82.1	4.8%	15.6%	33.0%	18.1%	20.7%	7.7%
Sweeper-Harold	22-Mar-10	7271	95.3	9.0%	18.9%	34.0%	16.9%	14.6%	6.5%
Sweeper-Ace	24-Mar-10	2718	82.8	16.7%	18.8%	27.5%	16.1%	14.7%	6.3%
Sweeper-Ace	8-Apr-10	516	80.8	9.8%	23.7%	28.0%	15.3%	16.5%	6.7%
Sweeper-Ace	26-Apr-10	665	109.3	6.1%	20.7%	35.6%	18.8%	14.0%	4.6%
Sweeper-Ace	25-May-10	413	77.8	7.6%	16.8%	28.4%	22.1%	18.2%	6.9%
Sweeper-Ace	1-Jun-10	161	67.3	9.1%	11.3%	24.9%	23.8%	22.5%	8.4%

Table B-3. Particle size and mass data for traction control samples.

			Particle Size (μm)						
Site	Date	Dry Mass (kg)	Mean	>2000	2000 - 500	500 - 125	125 - 62.5	62.5 - 17	≤16
Traction	24-Mar-09	245	344.6	42.9%	39.9%	15.3%	1.3%	0.8%	1.4%
Traction	22-Mar-10	210	273.7	40.9%	44.9%	11.4%	1.2%	0.7%	1.0%

Table B-4. Particle size and mass data for all sediment samples collected from three drop inlets on four dates.

				Percent Distribution by Particle Size (μm)					
DI	Date	Dry Mass (kg)	~D50	>2000	2000 - 500	500 - 125	125 - 62.5	62.5 - 17	≤16
Ace	25-Feb-09	24	190	7.1%	25.9%	24.4%	10.7%	18.7%	14.6%
College		56	450	15.4%	33.0%	24.6%	9.0%	11.0%	7.7%
Harold		63	160	3.5%	15.7%	36.5%	13.4%	20.5%	13.4%
Ace	12-Mar-09	5.5	400	13.6%	33.1%	29.4%	9.7%	9.2%	5.5%
College		4.2	480	18.5%	30.5%	28.7%	9.1%	8.9%	5.2%
Harold		85	175	3.5%	15.1%	39.6%	17.3%	17.3%	8.4%
Ace	17-Jul-09	8.6	210	9.8%	19.2%	33.9%	15.8%	11.8%	9.4%
College		22	95	12.0%	16.8%	15.5%	24.0%	23.8%	7.9%
Harold		16	250	16.6%	24.6%	21.8%	15.5%	12.9%	8.5%
Ace	24-Mar-10	69	800	17.0%	52.3%	21.8%	4.9%	3.1%	1.0%
College		101	700	22.9%	34.9%	17.9%	10.5%	10.2%	3.6%
Harold		32	100	9.0%	13.7%	21.9%	19.1%	24.0%	12.3%

Table B-5. Event mean particle size and mass data for all stormwater events. “Harold_1” is the first flush and “Harold_2” is the remainder of the event on 13 Oct 09. “Harold_A” is the washoff of the Harold study area and “Harold_B” is the washoff of the Ace study area sampled at Harold.

			Percent Distribution by Particle Size (µm)						
Site	Date	Mass (kg)	Mean	>1000	1000 - 500	500 - 125	125 - 62.5	62.5 - 17	≤16
Ace	29-Dec-08	35.7	9.2*	0.0%	0.0%	0.0%	0.0%	26.9%	73.1%
Harold	29-Dec-08	5.4	8.4*	0.0%	0.0%	0.0%	0.3%	24.7%	75.0%
Ace	22-Jan-09	2.0	4.3*	0.0%	0.0%	2.0%	1.6%	9.8%	86.7%
Harold	22-Jan-09	13.9	4.4*	0.0%	0.0%	0.1%	0.9%	14.4%	84.6%
Ace	24-Jan-09	4.2	5.0*	0.0%	0.0%	0.1%	3.6%	15.0%	81.3%
Harold	24-Jan-09	126.7	7.2*	0.0%	0.0%	1.0%	2.7%	21.9%	74.4%
Ace	22-Feb-09	24.0	4.7*	0.0%	0.0%	0.6%	3.2%	14.0%	82.2%
Harold	22-Feb-09	51.0	5.7*	0.0%	0.0%	0.5%	2.5%	17.9%	79.1%
Ace	24-Feb-09	0.3	4.4*	0.0%	0.0%	0.4%	4.0%	11.7%	83.9%
Harold	24-Feb-09	1.4	4.4*	0.0%	0.0%	0.1%	1.7%	12.6%	85.6%
Ace	2-Mar-09	3.8	6.3*	0.0%	0.0%	0.8%	3.9%	18.7%	76.6%
Harold	2-Mar-09	35.3	7.6*	0.0%	0.0%	0.6%	3.7%	23.3%	72.4%
Ace	21-Mar-09	4.2	8.3*	0.0%	0.0%	0.3%	4.4%	24.8%	70.4%
Harold	21-Mar-09	15.0	10.0*	0.0%	0.0%	0.3%	5.2%	29.1%	65.5%
Ace	25-Mar-09	0.4	3.7*	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Harold	25-Mar-09	0.2	4.1*	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Ace	1-May-09	7.7	5.4*	0.0%	0.0%	0.0%	0.0%	12.1%	87.9%
Harold	1-May-09	62.6	11.5*	0.0%	0.0%	0.8%	10.9%	29.4%	58.8%
Ace	28-Jul-09	5.7	3.8	0.0%	0.0%	0.0%	0.9%	10.7%	88.4%
Ace	13-Oct-09	21.9	20.4	0.0%	0.0%	7.8%	16.9%	30.7%	44.6%
Harold_1	13-Oct-09	8.5	18.9	0.0%	0.0%	8.8%	13.4%	29.4%	48.4%
Harold_2	13-Oct-09	64.3	23.0	0.0%	0.0%	9.5%	17.0%	32.9%	40.5%
Ace	20-Dec-09	2.4	3.8	0.0%	0.0%	0.0%	0.8%	11.1%	88.1%
Harold	21-Dec-09	3.8	6.2	0.0%	0.0%	1.1%	5.8%	18.3%	74.7%
Ace	24-Dec-09	3.7	4.4	0.0%	0.0%	0.0%	1.5%	12.9%	85.6%
Ace	6-Jan-10	3.6	3.6	0.0%	0.0%	0.3%	1.5%	9.9%	88.3%
Harold	6-Jan-10	0.3	2.9	0.0%	0.0%	0.0%	0.9%	6.6%	92.5%
Ace	7-Jan-10	2.0	4.3	0.0%	0.0%	0.2%	1.8%	11.6%	86.3%
Harold	7-Jan-10	2.5	3.9	0.0%	0.0%	0.0%	1.1%	11.0%	87.9%
Ace	8-Jan-10	15.1	6.2	0.0%	0.0%	1.1%	5.8%	18.3%	74.7%
Harold	8-Jan-10	6.9	3.8	0.0%	0.0%	0.0%	0.9%	10.7%	88.4%
Ace	12-Jan-10	12.7	4.4	0.0%	0.0%	0.0%	1.5%	12.9%	85.6%
Harold	12-Jan-10	22.8	3.8	0.0%	0.0%	0.0%	0.8%	11.1%	88.1%
Ace	17-Mar-10	0.7	4.7	0.0%	0.0%	2.8%	12.2%	36.2%	48.9%
Harold	17-Mar-10	-0.1	5.1	0.0%	0.0%	1.7%	10.2%	34.5%	53.6%
Ace_B	22-Mar-10	43.5	14.4	0.0%	0.0%	2.0%	11.2%	35.0%	51.9%
Harold_A	22-Mar-10	49.7	15.6	0.0%	0.0%	0.2%	1.3%	9.9%	88.5%
Harold_B	22-Mar-10	49.6	13.8	0.0%	0.0%	0.1%	1.8%	11.3%	86.7%
Ace	25-Mar-10	3.9	6.0	0.0%	0.0%	1.3%	2.4%	14.6%	81.6%
Harold	25-Mar-10	10.0	5.7	0.0%	0.0%	0.0%	0.8%	15.0%	84.2%
Ace	20-Apr-10	8.1	10.3	0.0%	0.0%	1.5%	6.5%	27.4%	64.5%
Harold	20-Apr-10	53.6	11.7	0.0%	0.0%	1.6%	7.4%	30.8%	60.2%
Ace	27-Apr-10	0.0	0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Harold	27-Apr-10	20.6	9.4	0.0%	0.0%	1.1%	5.4%	24.8%	68.6%
Ace	11-May-10	10.0	8.2	0.0%	0.0%	1.9%	5.9%	22.0%	70.2%
Harold	11-May-10	11.6	6.8	0.0%	0.0%	1.0%	3.2%	19.1%	76.7%
Harold	17-May-10	9.8	9.5	0.0%	0.0%	1.5%	5.5%	25.5%	67.5%
Ace_B	1-Jun-10	6.1	12.3	0.0%	0.0%	2.7%	16.3%	39.1%	41.8%
Harold_A	1-Jun-10	45.5	19.5	0.0%	0.0%	1.2%	7.9%	32.7%	58.2%
Harold_B	1-Jun-10	10.5	12.5	0.0%	0.0%	0.9%	7.0%	33.4%	58.7%

*Mean particle size was estimated

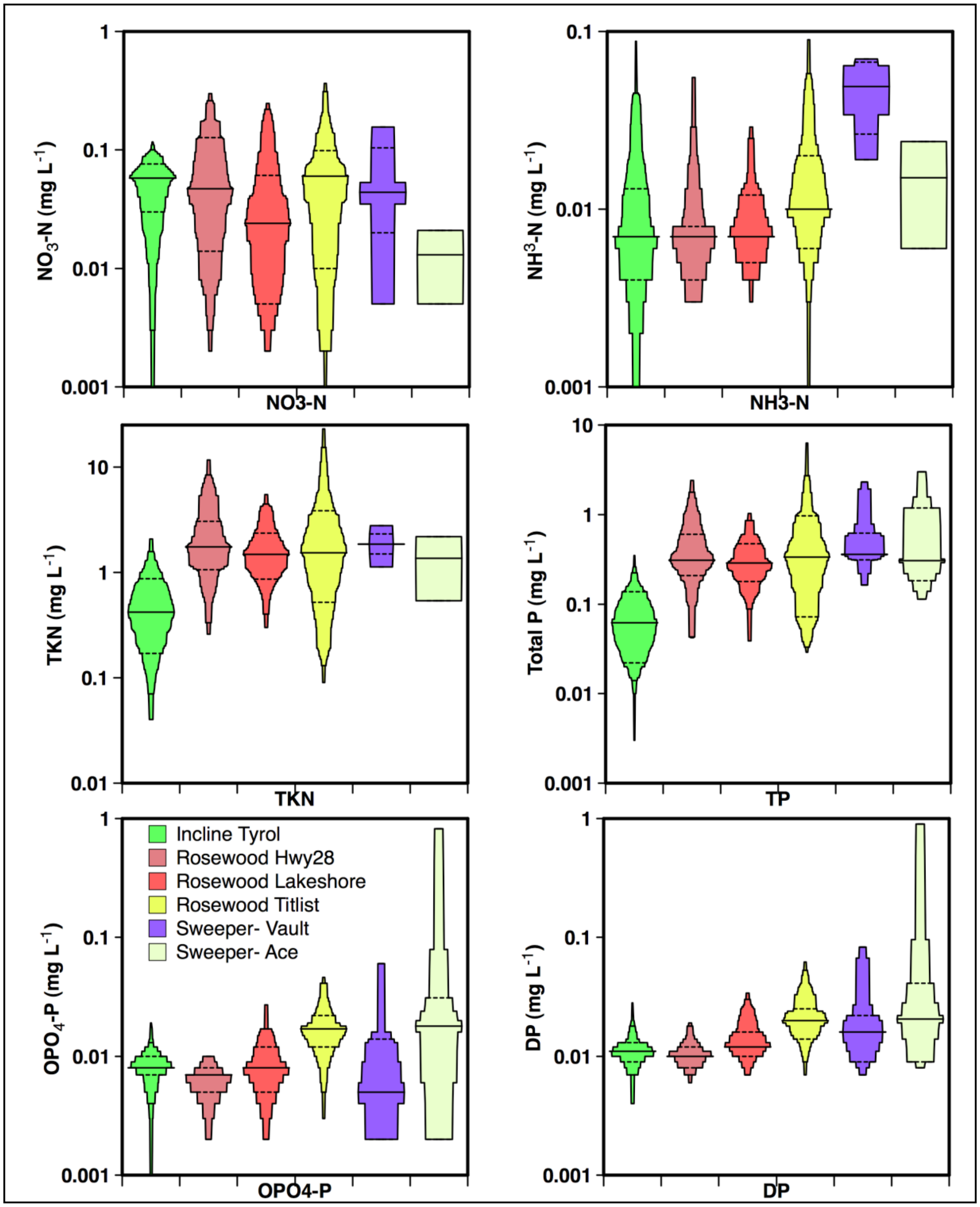

Figure B-1. A box-percentile plot of water chemistry data from Ace and Harold (aka "vault") compared to stream data. Incline Creek at Tyrol represents an undisturbed forested watershed (n=67, WY2002-WY2005). Rosewood Creek is the adjacent creek to this project site with samplers (WY 2008-2009) located just below the Highway 431 (Titlist, n=39), below Highway 28 (Hwy 28, n=33), and above Lakeshore Blvd (Lakeshore, n=35). Similar to a box-plot, the median value is denoted by the solid horizontal line and dashed lines denote the 25th and 75th percentiles. The width is proportional to the percent of observations.

Table B-6. Phosphorus fractions for selected stormwater events.

Date	Event	Sample Type	Site	OPO_4	DP	TP	TSS
				(mg/L)			
10/13/09	Rain	First flush composite	Harold	0.016	0.067	0.580	149
10/13/09	Rain	Second flush composite	Harold	0.060	0.083	0.311	78
3/22/10	Washoff	Event A composite	Harold	0.002	0.007	1.92	1,750
3/22/10	Washoff	Event A sample near peak flow	Harold	0.002	0.008	4.71	4,650
3/22/10	Washoff	Event B composite	Ace	0.002	0.008	3.01	2,920
3/22/10	Washoff	Event B sample near peak flow	Ace	0.002	0.009	8.44	9,040
3/22/10	Washoff	Event B composite	Harold	0.002	0.008	2.3	2,240

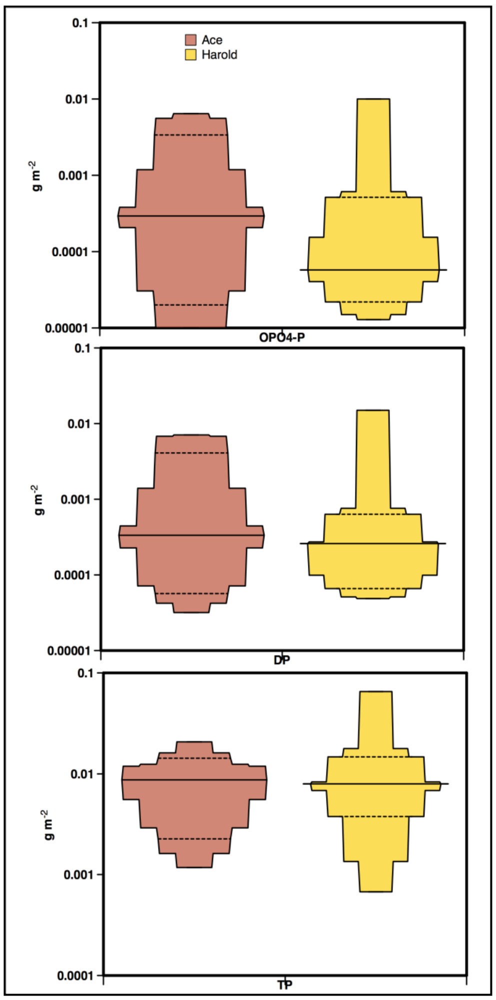

Figure B-2. Box-percentile plot of phosphorus water chemistry data as the load of P per road area for Ace (n=8) and Harold (n=9) monitoring sites. Harold includes inputs from both the Ace and Harold catchments.

Table B-7. Vacuum statistics for the Ace and Harold study areas in WY09 showing the load recovered from all transects before the road was swept and the average vacuum speed. The coefficient of variation (CV%) is provided to indicate the variability in the data for the collection date.

	Ace				Harold			
	Mass per linear meter vacuumed		Vacuum speed		Mass per linear meter vacuumed		Vacuum speed	
Date	g/m	CV%	in/sec	CV%	g/m	CV%	in/sec	CV%
12-Jan	1.8	16%	7.2	16%	2.6	43%	7.2	19%
20-Jan	0.64	60%	8.2	13%	0.52	48%	7.7	5%
27-Feb	1.9	36%	7.4	3%	3.3	22%	6.0	10%
12-Mar	1.5	10%	7.8	23%	2.3	41%	7.8	9%
Total			**7.6**	**15%**			**7.2**	**15%**

Table B-8. Vacuum statistics for the Ace and Harold study areas in WY10 showing the average vacuum speed. The coefficient of variation (CV%) is provided to indicate the variability in the speed for the collection date. No transects were vacuumed in the Ace study area for 6 Jan 2010.

	Ace		Harold	
Date	in/sec	CV%	in/sec	CV%
12/16 Oct 09	5.9	12%	5.2	8%
6 Jan 10	n/a		4.7	8%
1 Feb 10	4.8	14%	4.8	11%
22/24 Mar 10	5.6	16%	5.3	17%
8 Apr 10	5.1	3%	5.6	21%
26 Apr 10	5.8	12%	5.2	6%
25 May 10	6.1	9%	4.9	5%
1/2 Jun 10	6.2	15%	5.8	6%
Total	**5.8**	**16%**	**5.1**	**11%**

APPENDIX C: STUDY META DATA

The following meta data provides situational information for all samples.

Water Year 09

Washoe County swept Village Blvd, both Ace and Harold, in November 2008 prior to any sampling events; no sweeper sample or volume was collected.

Washoe County cleaned the DIs along Village Blvd in November 2008 prior to any sampling events; no DI samples or volume was collected.

29 Dec 2008

Stormwater Sample (Ace and Harold)- LPSA

Precip- snow Dec 24th, 25th & 26th
Plow- 14 of 17 days from Dec 13th-29th
Sand- 7 of 17 days from Dec 13th-29th, 168 lbs

12 Jan 2009

Reason for Vacuum/Sweep: After a precip event when roads were clear enough; 1st ever vacuum & sweep event

Precip- snow Jan 2nd & 5th
Plow- 4 of 11 days from Jan 1st-11th
Sand- Jan 2nd & 3rd, 81 lbs

Vacuum (Ace and Harold)
Sweep (Ace and Harold)
    Washoe County Tennant swept, 2.25yd^3 coarse, 0.25yd^3 fine
    NTCD collected a fine & coarse sample
Vacuum (Ace and Harold)
Sweep (Ace and Harold)
    Washoe County Tennant went back out and swept again; Dick Minto collected sample for NTCD, 0.25yd^3 coarse, 0.25yd^3 fine

- Not able to vacuum or sweep from curb to curb because of snow/ice berm

Site Name	Total Vacuumed Length per section	Total Length per section	% Vacuumed per section	Area Vacuumed per section (ft^2)
vac_12jan09_ace_A_before	218.9	242.8	90%	145.9
vac_12jan09_harold_A_before	136.7	158.3	86%	91.1
vac_12jan09_ace_B_after	189.3	218.6	87%	126.2
vac_12jan09_harold_B_after	139.7	157.6	89%	93.2

20 Jan 2009

Reason for Vacuum/Sweep: Expected precip occurred on Jan 22nd, 23rd & 24th

No precip, plow or sand since 12 Jan dry sample event

Vacuum (Ace and Harold)
Sweep (Ace and Harold)
Washoe County Tennant swept, 0.50yd^3 material
Vacuum (Ace and Harold)

Washoe County Tennant collected very little material, which was good since no material had been applied since the 12Jan09 vacuum/sweep.

- Not able to vacuum or sweep from curb to curb, assume snow/ice berm

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_20jan09_ace_B_before	191.9	218.6	88%	128.0
vac_20jan09_harold_B_before	139.8	157.6	89%	93.2
vac_20jan09_ace_A_after	214.1	242.8	88%	142.7
vac_20jan09_harold_A_after	140.5	158.3	89%	93.6

22 Jan 2009

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- rain on snow (0.56inches)

24 Jan 2009

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- rain/snow mixture

04 Feb 2009

Reason for Sweep: Dry sample event performed immediately before major snow storm was expected.

Precip - Jan 22nd & 23rd, 0.56in & 0.40in respectively
Plow- Jan 24th, 25th & 26th
Sand – Jan 25th & 26th, 122 lbs

Sweep
Washoe County Tennant swept, able to get into curbs & gutters for the 1st time.
3.32yd^3 coarse, 0.80yd^3 fine

22 Feb 2009

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- rain on snow (0.68inches)

24 Feb 2009

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- rain/snow mixture

25 Feb 2009

DIs were cleaned by NTCD for the first time at Ace, College, and Harold. Removed all sediment material.

27 Feb 2009

Reason for Vacuum/Sweep: Roads somewhat dry after a month of precip
Precip- snow/precip 15 out of 22 days from Feb 4th-26th
Plow- 16 of 22 days from Feb 4th-26th
Sand- 9 of 22 days from Feb 4th-26th, 342 lbs

Vacuum (Ace and Harold)
Sweep (Ace and Harold)
Washoe County Tennant swept- 0.90yd^3 coarse, 0.03yd^3 fine
Vacuum (Ace and Harold)

- Curbs/gutters covered with snow/ice, so not all of road was swept or vacuumed.

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_27feb09_ace_A_before	171.3	242.8	71%	114.2
vac_27feb09_ace_B_after	165.9	218.6	76%	110.6
vac_27feb09_harold_A_before	143.3	158.3	91%	95.6
vac_27feb09_harold_B_after	142.4	157.6	90%	94.9

2 Mar 2009

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- rain/snow mixture (0.39inches)

12 Mar 2009

Reason for Vacuum/Sweep: Roads somewhat dry after first 11 days of month receiving precip.

Precip- Snow/precip 7 of 11 days from March 1st-11th
Plow- 7 of 11 days from March 1st-11th
Sand- 2 of 11 days from March 1st-11th, 22 lbs

Vacuum (Ace and Harold)
Sweep (Ace and Harold)
Washoe County Tennant swept, 0.56yd^3 coarse, 0.04yd^3 fine
Vacuum (Ace and Harold)
DIs were cleaned at Ace, College, and Harold. Removed all sediment material.

- Not able to vacuum or sweep from curb to curb

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_12mar09_ace_A_after	207.1	242.8	85%	138.1
vac_12mar09_ace_B_before	198.0	218.6	91%	132.0
vac_12mar09_harold_A_after	130.6	158.3	82%	87.0
vac_12mar09_harold_B_before	134.0	157.6	85%	89.3

21 Mar 2009

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain/snow mixture

24 Mar 2009

Traction Control sampled collected and analyzed

25 Mar 2009

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain

10 Apr 2009

Stormwater Sample (Ace and Harold)- no analysis
Precip- snow

01 May 2009

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain

01 Jun 2009

Stormwater Sample (Ace and Harold)- water chemistry
Precip- thunderstorm, rain (0.01in)

23 Jun 2009

Traction control sample collected and analyzed

17 Jul 2009

DIs were cleaned at Ace, College, and Harold. Removed all sediment material.

28 Jul 2009

Stormwater Sample (Ace and Harold)- LPSA for Ace only
Precip- thunderstorm, rain (0.02in)

Water Year 10

Washoe County swept Village Blvd, Ace and Harold, in November 2009 after the October 13th rain event, but prior to all other Year 2 sampling events; no sweeper sample or volume was collected.

Washoe County cleaned the DIs along Village Blvd in November 2009 after the October 13th rain event, but prior to all other Year 2 sampling events; no DI samples or volumes were collected.

Village Blvd was next swept, Harold only, on January 6th, 2010 during a vacuum/sweep event

Harold section of the Sweeper Study was not swept from March 23rd, 2010 until after June 2nd, 2010.

12 & 16 Oct 2009

Reason for Vacuum: Large precip event expected on 13 October
Stormwater Sample (Ace and Harold, Oct 13th)- LPSA and water chemistry
Precip- rain Oct 13th (1.7inches); August 23rd small rain event (no accumulation)
Plow- Unknown
Sand- None

Vacuum (Ace and Harold) - 12oct09
Stormwater Sample (Ace and Harold) – 13oct09
Vacuum (Ace and Harold) - 16oct09

- Washoe County Tennant did not sweep
- NTCD able to vacuum from curb to curb

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_12oct09_ace_A_before	242.8	242.8	100%	161.9
vac_12oct09_harold_A_before	158.3	158.3	100%	105.5
vac_16oct09_ace_B_before	218.6	218.6	100%	145.8
vac_16oct09_harold_B_before	157.6	157.6	100%	105.1

20 Dec 2009

Stormwater Sample (Ace)- LPSA
Precip- Unknown, snow on Dec 16th

21 Dec 2009

Stormwater Sample (Harold)- LPSA
Precip- rain, snow (0.06in)

24 Dec 2009

Stormwater Sample (Ace)- LPSA
Precip- rain, snow Dec 21st, 22nd and 23rd (0.06in, 0.02in and snow respectively)

06 Jan 2010

Reason for Vacuum/Sweep: Roads were somewhat dry in between snow, snowmelt and rain events that happened before and after Jan 6th

Stormwater Sample (Ace and Harold)- LPSA

Precip- Snow Dec 28th & 30th – 0.10in & 0.04in respectively
Plow- Unknown
Sand- Dec 22nd, 23rd, 29th & 30th; Ace- 98 lbs, Harold- 96 lbs

Vacuum (Harold only)
Sweep (Harold only)
Washoe County Tennant swept, 1st sweep of the season since November 2009; 0.91yd^3 total
Vacuum (Harold only)

- Washoe County swept the dry portions of Harold
- Ace (Upper) site too wet- did not vacuum or sweep!
- Harold sampling greatly restricted due to ice, snow, and melt water
- NTCD was only able to vacuum the east side (right side when driving uphill) of the road from curb to center yellow line; west side of road not vacuumed at all because too wet

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_06jan10_harold_B_before	67.0	157.6	43%	44.7
vac_06jan10_harold_A_after	66.0	158.3	42%	44.0

Ace remained unswept from November 2009 thru March 22, 2010

07 Jan 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain Jan 6th

08 Jan 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain Jan 6th

12 Jan 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain Jan 9th (0.03in) and rain, snow Jan 12th (0.14in)

28 Jan 2010

Snow core samples collected

01 Feb 2010

Reason for Vacuum/Sweep: Received precip prior to event and precip expected Feb 2nd & 4th (0.06in snow and 0.04in rain/snow mixture)

Precip – Jan 25th, 26th & 28th- 0.04in, 0.04in, 0.13in respectively
Plow- Unknown
Sand- Jan 13th, 19th-22nd; Ace- 147 lbs, Harold- 158 lbs

Vacuum (Ace* and Harold)
    *Ace transect L1A lost vacuum suction and approximately 10grams of material was left in vacuum and not in vacuum bag.
Sweep (Harold)
    Washoe County Tennant swept Harold only, 1.31yd^3 total
Vacuum (Harold)

- Assume Washoe County swept from curb to curb, but gutters were moist with sediment caked on
- NTCD could not vacuum curbs/gutters because they were wet & sediment caked on

Site Name	Total Vacuumed Length per	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)

	Section			
vac_01feb10_harold_A_before	140.4	158.3	89%	93.6
vac_01feb10_ace_A_before	176.4	242.8	73%	117.6
vac_01feb10_harold_B_after	136.5	157.6	87%	91.0

The sweeper was down from February 11th-23rd, 2010.

Ace remained unswept from November 2009 thru March 22, 2010

17 Mar 2010

Stormwater Sample (Ace and Harold)- LPSA

Precip- snow Mar 10th, 12th and 13th (0.09in, 0.02in and snow respectively); assume sample from snowmelt

22 & 24 Mar 2010

Reason for Vacuum/Sweep: Rain Simulator Event
Precip- snow Mar 10th & 12th (0.09in and 0.02in respectively)
Plow- Unknown
Sand- Mar 2nd, 7th and 10th; Ace- 45 lbs, Harold- 27 lbs

<u>March 22nd</u>
Vacuum (Ace, Harold and 14th Green)
Sweep (Harold)

1. The sweeper had to be emptied 3 times until the road was considered swept to Washoe County's standards
2. NTCD collected 6 different sweeper samples- a fine & mixed (coarse & fine material together) sample for each sweeper load.
3. NTCD also measured the volume of the mixed sweeper loads (2.6yd^3, 2.65yd^3, 1.08yd^3 respectively)
4. NTCD dried & sieved each individual sample, then combined the sub 16 µm portion of the mixed samples into a single composite based on the volume of each sweeper load
    a. ***sweeper_22mar10_harold_mixall_F***

Vacuum (Harold)
Rain Trucks (Harold 1st, Ace 2nd)
Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Vacuum (Harold)
Traction control sample collected
Traffic Tubes installed downhill of Golfers Pass
Golfers Pass DI water sample collected

<u>March 24th</u>
Vacuum (Ace)
Sweep (Ace)

1. The sweeper had to be emptied 2 different times
2. NTCD collected 4 different sweeper samples- a fine & mixed (coarse & fine material together) sample for each sweeper load
3. NTCD also measured the volume of the mixed sweeper loads

4. NTCD dried & sieved each individual mixed sample, then created a single composite based on the volume of each sweeper load
    a. ***sweeper_24mar10_ace_mixall_F***

Vacuum (Ace)

DI core samples were collected at Ace, College, and Harold.

1. DI samples were collected in 2.3 liter bottles
2. NTCD needed the density, so sample was homogenized, and subsamples were put in 500ml bottles
3. Harold has one sample due to lack of material, Ace & College each have two samples
4. NTCD measured a wet density and a dry density
5. Samples were then sieved
    a. ***DI_24mar10_harold1_F***
    b. ***DI_24mar10_college1_F***
    c. ***DI_24mar10_college2_F***
    d. ***DI_24mar10_ace1_F***
    e. ***DI_24mar10_ace2_F***

Snow core samples collected

1. NTCD & DRI collected 2 sets of snow core samples from both sides of the road at two locations
    a. Samples & data went directly to DRI with Brian Fitzgerald

No precip from March 14th-21st.

Ace remained unswept from November 2009 thru March 22, 2010

- March 22nd- Not able to sweep or vacuum from curb to curb
- March 24th- almost able to vacuum from curb to curb (inches away instead of feet).

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_22mar10_harold_A_before	149.1	158.3	94%	99.4
vac_22mar10_ace_A_before	226.9	242.8	93%	151.3
vac_22mar10_harold_B_after	156.8	157.6	99%	104.5
vac_22mar10_harold_A_afterrain	92.2	96.9	95%	61.5
vac_24mar10_ace_A_afterrain	241.2	242.8	99%	160.8
vac_24mar10_ace_B_after	216.6	218.6	99%	144.4

*Only 3 of 5 transects on Harold section were vacuumed due to pavement being too wet.

For the Sweeper Study winter 2010, Washoe County swept the Harold section ONLY from November 2009 through March 22, 2010.

After March 22, 2010, Washoe County swept the Ace section ONLY.

The Washoe County sweeper had to empty the sweeper 3 different times while sweeping the Harold section ONLY. NTCD collected a fine sweeper sample each time. The numbers: fines1, fines2, and fines3 represent the samples collected.

For the March 22, 2010 fine samples:

sweeper_22mar10_harold_fines1
sweeper_22mar10_harold_fines2
sweeper_22mar10_harold_fines3

The Washoe County sweeper had to empty the sweeper 2 different times while sweeping the Ace section ONLY. NTCD collected a fine sweeper sample each time. The labels “fines1” and “fines2” represent the samples collected.

For March 24, 2010 fine samples:

sweeper_24mar10_ace_fines1
sweeper_24mar10_ace_fines2

25 Mar 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- snow Mar 25th (0.09in)

08 April 2010

Reason for Vacuum/Sweep: A break in snow showers with dry roads.

Precip – April 2nd, 4th & 5th - 0.03in, 0.08in, 0.12in respectively
Plow- Unknown
Sand- None

Vacuum (Ace and Harold)
Sweep (Ace)
Washoe County Tennant swept, 0.45yd^3 mixed, 0.02yd^3 fine
Vacuum (Ace)

- Assume Washoe County swept from curb to curb, but gutters probably wet so not all material was picked up
- NTCD not able to vacuum curb/gutters because wet (within 0 to 18inches from curb)

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_08apr10_ace_A_before	228.1	242.8	94%	152.0
vac_08apr10_harold_A_before	148.1	158.3	94%	98.7
vac_08apr10_ace_B_after	204.0	218.6	93%	136.0

Harold remained unswept from March 23rd thru the end of the study.

20 April 2010

Stormwater Sample (Ace and Harold)- LPSA and water chemistry
Precip- snow Apr 20th (slushy snow)

26 April 2010

Reason for Vacuum/Sweep: Precip expected Apr 27th- 0.12in rain/snow

Precip – April 20th, 21st & 22nd - .15in, .26in, 0.14in respectively
Plow- Unknown
Sand- None

Vacuum (Ace and Harold)

Sweep (Ace)
*Washoe County Tennant accidentally swept below Ace down to Driver Way on both curb sides- 400ft each side
Washoe County Tennant swept Ace only*- 0.58yd^3 mixed
Vacuum (Ace)

- Able to sweep & vacuum from curb to curb- mostly!

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_26apr10_ace_A_before	241.1	242.8	99%	160.7
vac_26apr10_harold_A_before	158.3	158.3	100%	105.5
vac_26apr10_ace_B_after	217.0	218.6	99%	144.6

Lots of sediment visible on Ace, but no sanding had occurred since March 10th (12 lbs). Run for finger-printing! (vac_26apr10_ace_A_before)

Harold remained unswept from March 23rd thru the end of the study

27 Apr 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- rain, snow Apr 27th (0.12in)

11 May 2010

Stormwater Sample (Ace and Harold)- LPSA
Precip- snow May 11th (0.01in), sample most likely from snowmelt on May 9th and 10th

17 May 2010

Stormwater Sample (Ace and Harold)- LPSA for Harold
Precip- rain May 17th

25 May 2010

Reason for Vacuum/Sweep: Precip expected May 26th, 27th & 28th, rain/snow mixture, low accumulation

Precip – rain/snow mixture May 17th-19th and 21st-23rd
Plow- Unknown
Sand- None

Vacuum (Ace, Harold and 14th Green)
Sweep (Ace)
Washoe County Tennant swept Ace only, 0.36yd^3 mixed
Vacuum (Ace)

- Able to sweep & vacuum from curb to curb

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)

vac_25may10_ace_A_before	242.8	242.8	100%	161.9
vac_25may10_harold_A_before	158.3	158.3	100%	105.5
vac_25may10_ace_B_after	218.6	218.6	100%	145.8

Harold remained unswept from March 23rd thru the end of the study

01 & 02 Jun 2010

Reason for Vacuum/Sweep: Rain Simulator Event; precip expected Jun 3rd- 0.04in rain

Precip- snow May 26th, 27th & 28th- .01in, 0.10in and dusting respectively
Plow- Unknown
Sand- None

01Jun10
Vacuum (Ace and Harold)
Sweep (Ace and 14th Green)
    Washoe County Tennant swept, 0.14yd^3 mixed
    Vacuum (Ace and 14th Green)
Vacuum longitudinal (Ace and Harold)
Rain Simulator (Harold 1st, Ace 2nd)
Stormwater Sample (Ace and Harold)- LPSA
El Dorado County/Russ Wigart performed Road RAM & personal rain simulator on 14th Green

02Jun10
Vacuum afterrain (Ace and Harold)

- Able to Vacuum & Sweep from curb to curb

Site Name	Total Vacuumed Length per Section	Total Length per Section	% Vacuumed per Section	Area Vacuumed per Section (ft^2)
vac_01jun10_ace_B_before	218.6	218.6	100%	145.8
vac_01jun10_harold_B_before	157.6	157.6	100%	105.1
vac_01jun10_ace_A_after	242.8	242.8	100%	161.9
vac_02jun10_ace_A_afterrain	242.8	242.8	100%	161.9
vac_02jun10_harold_A_afterrain	158.3	158.3	100%	105.5